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ORIGINAL ARTICLES.

The Dykes of the Ards Peninsula, Co. Down.

By D. L. Reynolds, M.Sc.

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1. INTRODUCTION.

THE Ards peninsula, which forms the eastern part of Co. Down, is about 20 miles long and varies from 3 to 5 miles in breadth. On the west it is separated from the mainland by Strangford Lough, the east coast facing the Irish Sea.

The country rocks are slates and grits of Silurian age, with a prevalent S.W.–N.E. strike and a high angle of dip, the direction of which varies due to a succession of folds which date from Caledonian times. Into this series numerous dykes are intruded, the great majority of which have their strike coincident with that of the country rocks, the remainder taking a direction at right angles, or rarely at 30° to this. These intrusions form a part of a great series of dykes which occur throughout the north of Ireland, cutting the Caledonian folds, but nowhere penetrating the Carboniferous strata.

Previous knowledge of the Ards dykes is due to the Geological Survey,[1] who mapped them, recorded their main exposures and

[1] Expl. Sheets 49, 50, and part of 61, *Geol. Surv. Ireland*, 1871, 36–45; Expl. Sheets 37, 38, and part of 29, 1871, 25–29, 32–33.

first classified them as intrusive felstones, minettes and diorites, together with ashes of Silurian age. Later McHenry and Watts,[1] in a brief account of the intrusions, described them as lamprophyres belonging to the groups of minettes and kersantites. In 1899 Seymour and Egan [2] revised the igneous geology of the Ards, and, after a study of thin sections, Seymour found all the rocks to be lamprophyres, the varieties of which differ from one another in the fact that the predominating ferro-magnesian mineral is sometimes biotite, sometimes hornblende, and more rarely augite. Believing plagioclase to be the most abundant felspar, he classified them as kersantites and camptonites.

Nothing is known of the relation of the various types of rock and practically nothing of their petrology. The present study was undertaken to correct the early classification, to determine the distribution of rock types and their order of intrusion and, if possible, to gain some insight into their origin. The investigation was restricted to coast exposures, the greater part of the interior being under cultivation. The Strangford and Irish Sea coastlines of the Ards, however, provide a double traverse across the strike of the country rocks and 260 dykes were examined.

2. GENERAL FIELD RELATIONS.

The distribution of the dykes round the shore is indicated on the sketch map, Fig. 1. In the field they can be separated into two series, according to age. Those which occur in the south, whilst penetrating and truncating folds in the Silurians, are themselves cleaved and crushed, frequently having the appearance of schists. The majority follow the strike of the Silurian slates and grits, and the foliation is parallel to their sides. They were evidently intruded during a pause in the Caledonian folding, continuation of pressure in approximately the same direction afterwards reducing them to a schistose state.

The younger series is practically confined to the north of the area, and the majority of the dykes again have a prevalent S.W.–N.E. strike. They are not seen in contact with the older series, but are noticeably different, being fresher, more massive, and showing no signs of crush.

Similar relations between lamprophyre dykes and earth-movements occur in Colonsay, where the varied age of the intrusions as related to cleavage has been described by Wright [3] and in the *Geological Survey Memoir* of the district.[4] The early lamprophyres

[1] *Guide to the Collections of Rocks and Fossils belonging to the Geological Survey of Ireland*, 1898, 74–5.

[2] *Summ. Progr. Geol. Survey*, 1899, 180–1.

[3] W. B. Wright, "The Two Earth-Movements of Colonsay": *Quart. Jour. Geol. Soc.*, lxiv, 1908, 297–311.

[4] "The Geology of Colonsay and Oronsay": *Memoir Geol. Survey Scotland*, 1911, 38 and 39.

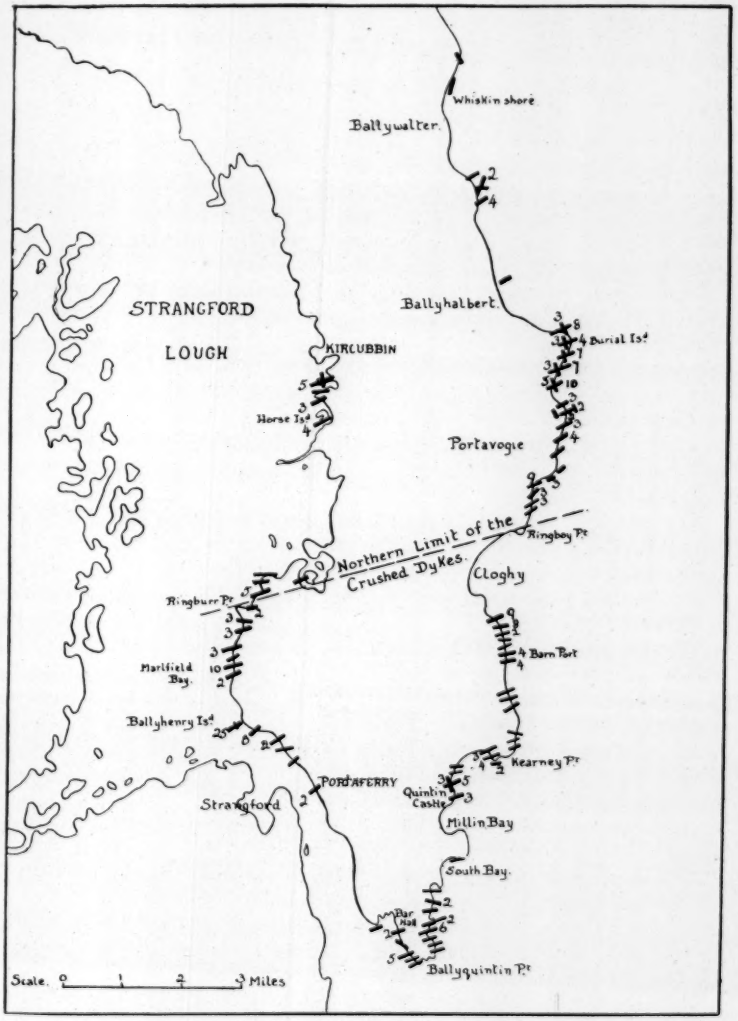

FIG. 1.—Map showing the general distribution of the dykes around the coast of the Ards Peninsula. Owing to the small scale of the map it has been found necessary in many instances to group the dykes and in these cases the numerals indicate the number of them represented by each line. For the same reason groups of dykes are shown as intersecting on the map, whereas in reality a few members only are in contact.

of the Ards, however, although greatly crushed, have not been folded by the later movements. Normal and sheared lamprophyres, together with lamproschists, are also recorded from the Ben Wyvis [1] area and crushed lamprophyres from the Isle of Man.[2]

In addition to numerous dykes with a strike parallel to that of the Caledonian folds, both the older and newer series include a smaller number of members which cut these and have a strike at right angles to the axis of folding. The evidence of regional tension which such conjugate intrusions afford has been discussed by Evans.[3] Applying his conclusions in the case of the Ards dykes, it appears that both the crushed and uncrushed series were intruded during periods of tension which occurred as a reaction after Caledonian compression. In each case there was stretching in all directions, varying from a maximum perpendicular to the axis of folding to a minimum parallel to it. Consequently, at both periods, splitting, accompanied by dyke intrusion, took place first parallel to the folds and released all the components of tensional force perpendicular to that direction. The only forces remaining then being parallel to what was the direction of minimum tension, there was subsequent splitting and dyke intrusion on a smaller scale at right angles to the folds.

The crushed series of dykes thus afford evidence of a distinct pause in the Caledonian compression, during which pressure was relaxed and tensional forces came into play. It is worthy of note that after the final period of stress the site of igneous activity had moved northward.

The total thickness of the crushed dykes intruded parallel to the strike of the country rocks, as measured on the east coast, is 102 feet. There was thus a stretching of the earth's crust by this amount in a north-westerly direction, in a distance of 5·6 miles, as a result of the first period of tension. That is, the earth's crust was lengthened in the direction of maximum tension by ·3 per cent. This estimate must be regarded as a minimum, since it is likely that dykes are concealed both in the sandy bays and in seaweed-covered areas.

The combined thickness of the younger dykes, intruded parallel to the bedding, and exposed on the east coast is 488 feet. These dykes occur within 9·6 miles of country, measured at right angles to the strike. In this case, therefore, the earth's crust was lengthened by 1 per cent.

In addition to the two definite series of intrusions described, there are a few dykes of pyroxene-minette exposed between Ringburr Point and Old Man's Head, including the dyke at the latter locality, which cannot be definitely assigned to either series. In the field they

[1] "Geology of Ben Wyvis, etc.": *Mem. Geol. Surv. Scotland*, 1912, 116–26.
[2] "Geology of the Isle of Man": *Mem. Geol. Surv.*, 1903.
[3] J. W. Evans, *Pres. Add. Geol. Soc., Quart. Jour. Geol. Soc.*, lxxxi, 1925, lxxxvi.

are seen to be cleaved, but are not foliated like the older dykes. Petrologically they resemble the younger type. A dyke of vogesite, outcropping on the northern shore of South Bay is also cleaved, but has not been rendered schistose and petrologically resembles some of the vogesites of the newer series. It is possible that these dykes may be intermediate in age, and it is striking that on the west coast they are intermediate in position between the older and younger series.

3. THE OLDER OR CRUSHED DYKES.

(*a*) Field Description.

Intrusions belonging to the older series are not found north of Ringburr Point on the west coast, or north of Slanes Point on the east, but in the absence of exposures in the sandy Cloghy Bay the northern limit for the crushed dykes has been drawn on the map from Ringburr to Ringboy Points, thus following the strike of the country rocks.

The members of this series are all narrow, as is apparent from the following summary of the thickness of 101 dykes which were measured :—

Thickness.	*Number.*
1 ft. and under . .	35
1 ft. to 2 ft. . .	37
2 ft. to 3 ft. . .	17
3 ft. to 4 ft. . .	5
4 ft. to 5 ft. . .	2
5 ft. to 6 ft. . .	5

Thus of the measured dykes 88 per cent have a thickness of only 3 feet or less.

With the exception of two or three pinkish rocks, the dykes are grey, or greenish grey, in colour and are not easily recognized in the field, for they closely resemble the almost vertical slates and grits into which they are intruded and are frequently buried in seaweed. The cleavage of the slates is often seen to continue through them, and they show a marked foliation, sometimes appearing schistose.

At first sight the majority resemble sills, since they follow the strike of the sedimentary beds, but closer inspection reveals the fact that while some wind across the strike of the Silurians in places, or truncate crumples, others transgress in the vertical sense, either piercing their way through the crests of small folds or exhibiting an angle of dip which differs from that of the sediments. Very rarely, almost vertical dykes cut across the strike of the country rocks at approximately 3°. Examples occur at the southern end of Ballyhenry Island and to the north of Lower Ballyspurge.

Dykes which cut the strike of the Palaeozoic rocks at right angles

are not common. These are usually sheet-like in character, and rarely have a dip of more than 30°, the direction being variable. Wherever they are seen in contact with the sill-like dykes, they cut through them. This relationship is well exhibited in a small bay just to the north of Quintin Castle, where several dykes with a strike parallel to that of the slates occur, and three others with a N.N.W. strike cut the slates at right angles. Two of the latter cut across the former, the more easterly of the two also truncating small folds in the slates.

An interesting dyke occurs at Kearney Point, where it appears in detached horizontal portions extending in an E.N.E. direction. It varies from 10 to 14 inches in thickness, and rests on the upturned edges of a series of small folds in the Silurians. Traced eastward, it develops a dip of about 22° to the S.E., and passes into the sedimentary rocks.

There are no composite dykes, but one multiple intrusion was noted at the southern end of Ballyhenry Island. The members, intruded side by side and occasionally separated by an inch or two of slate, measure respectively 8 and 5 inches across. They cut the bedding and cleavage of the slates at 30°, striking 8° N. of E.

(*b*) Petrology.

Members of the crushed series are all lamprophyres, and are usually in an advanced stage of decomposition and highly charged with carbonates, largely due to infiltration along the planes of schistosity and replacement of the felspars. Qualitative chemical tests indicate the presence of lime, iron, and magnesium carbonates. Minerals which were originally characteristic of these rocks are potash-felspar, plagioclase, biotite, monoclinic pyroxenes, olivine, and quartz, with apatite, magnetite and iron pyrites as accessories. Hornblende was present in rare instance only.

The rocks are minettes and rarely vogesites, since in every case in which the felspars are still recognizable potash-felspar predominates. From its patchy extinction this felspar is probably anorthoclase. Plagioclase is always present, and occasionally almost equals anorthoclase in amount. It gives a maximum extinction of 16° in the zone normal to (010), is optically positive with $\gamma < 1{\cdot}54 > 1{\cdot}536$, $\alpha < 1{\cdot}532 > 1{\cdot}528$, and consequently can be assigned to albite.

Biotite is the only ferromagnesian mineral which ever appears fresh; even here, however, freshness is the exception and decomposition to a chloritic substance with sagenite nets is usual, lenticles of calcite being frequently intruded between the cleavage planes. Well formed crystals are often observed, in addition to ragged flakes, and zoning is common.

A monoclinic pyroxene is represented in many of the rocks by pseudomorphs of carbonates and quartz, whilst lozenge-shaped pseudomorphs, also of carbonates and quartz and rimmed tangen-

tially by biotite, indicate the former presence of olivine in some specimens.

There is usually a little interstitial quartz and frequently a small amount of a pale green glass, which will receive further description in connection with the newer intrusions, where it also occurs and is more easily examined. Muscovite is sometimes present as a decomposition product.

Vogesites are uncommon, rare dykes only containing pseudomorphs after hornblende, in which case pyroxene and mica seem to have been absent.

Speaking generally, the proportion of felspar to ferro-magnesian minerals is higher in these rocks than in the younger series.

The texture is variable and does not depend altogether on the size of the intrusions. In some, the felspars are elongated and irregular in shape, averaging 0·6 mm. by 0·4 mm., whilst in others they form plumose aggregates and the structure approaches the spherulitic. The latter texture is sometimes found in dykes which are 2 feet or more in thickness, whilst the former, although characteristic of the larger intrusions, may appear in those which are only 10 inches in width. In some dykes the felspars have a lath-like form, the minute laths being separated by interstitial quartz and green glass. Two narrow dykes, one 10 inches thick at Kearney Point and another 6 inches thick at Barn Port, are distinctly spherulitic towards the centre, the crowded spherulites being embedded in a green glass which is crowded with secondary sericite. These rocks contain pseudomorphs after biotite with a linear arrangement due to flow ; the pseudomorphs are present both in the spherulites and in the glassy matrix, indicating the intratelluric origin of the biotite. The specific gravity of the central spherulitic portion of the dyke at Barn Port is 2·767 at 4° C.

Rounded xenocrysts of quartz are common, and are bordered by a narrow reaction-rim now composed of carbonates. Xenoliths of quartzite are also frequently seen in thin section. Both xenoliths and xenocrysts have evidently been derived from the country rocks.

The ocellar structure, so often described in lamprophyres, is developed in some members of the crushed series. Bodies which are circular or oval in section are scattered through the rock, and contain anorthoclase, plagioclase, calcite, and a little quartz. The plagioclase is usually euhedral, whilst anorthoclase may be euhedral or anhedral. Quartz and calcite are always interstitial. The felspars are sometimes noticeably more coarsely crystalline than those of the matrix. These structures are rimmed tangentially by flakes of biotite. They show no definite internal arrangement, the enclosed minerals being disposed quite irregularly, or extending from side to side. Sometimes a felspar inside the structure extends beyond the biotite rim.

Signs of crush can be seen in thin section, although they are more evident in hand-specimens. Biotite flakes are sometimes

bent and in a few of the dykes the felspar matrix has undergone granulitization, a mosaic structure resulting. The minerals frequently show a parallelism which is probably partly due to an original flow structure and partly to crushing, and the foliation has been accentuated by the infiltration of carbonates along the lines of schistosity. Most of the quartzite xenoliths show a lenticular form, with their long axes parallel to the schistosity of the matrix.

4. THE YOUNGER OR UNCRUSHED DYKES.

(*a*) Field Description.

(i) Distribution.

The younger dykes have their greatest development north of the limit of the crushed series, a few isolated examples only outcropping in the south ; notable occurrences being :—

1. At the point north of Barhall, where just above low-water-mark a dyke of pyroxene-minette, about 4 feet thick, cuts the bedding of the country rocks and shows a variable dip which at its maximum is 38° to the west of north.

2. In Marfield Bay, where a vogesite dyke, approximately 7 feet wide, strikes 12° east of north-east parallel to the bedding of the country rocks.

3. Opposite Templecowey, a dyke of pyroxene-minette 10 feet wide, strikes 3° north of east parallel to the country rocks.

4. South of Slanes Bay a red felspar-porphry 2 ft. 6 in. wide strikes 3° north of east.

(ii) Types of Rock and their Order of Intrusion.

Dykes belonging to the younger series are of two main types: one characterized by hornblende and the other by biotite and monoclinic pyroxene. The former is predominantly red, whilst the latter is usually brown, with lustrous flakes of dark mica. It is not always possible, however, to distinguish between the two varieties in the field. Dykes containing hornblende form the most massive intrusions in the district and with one exception, on the headland south of Kircubbin, always follow the strike of the country rocks, whilst dykes bearing biotite and pyroxene occur both parallel to the strike of the country rocks and cutting it and the hornblende dykes at right angles. In no case does a hornblende dyke cut one containing biotite or pyroxene. Consequently it can be inferred that the hornblendic type was the first to be intruded. This relation between the two varieties is best exposed along the shore between Portavogie and Burial Island.

Intrusions characterized by hornblende belong to the four following types : —

Hornblende-porphyrite.
Vogesite.
Spessartite.
Felspar-porphyry.

Hornblende-porphyrite, which forms the largest intrusions, is red in colour, with phenocrysts of green hornblende and felspar, the former being the more abundant. One dyke, 25 feet wide, is exposed in the sand on the shore south of Portavogie;

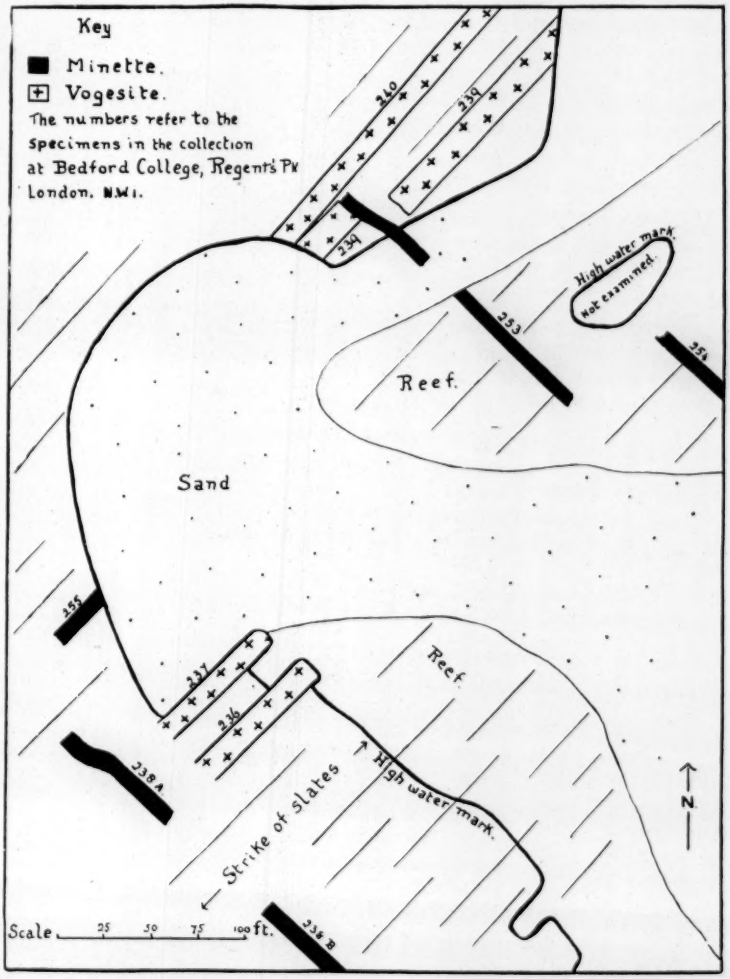

FIG. 2.—Map of part of the coast at the headland north of Portavogie illustrating the relation of hornblende- and biotite-diopside-bearing dykes.

another, 45 feet wide, outcrops slightly farther north, where it forms a low cliff and extends under the road opposite some cottages. A hornblende-porphyrite dyke 40 feet wide also outcrops at the quay, Portavogie.

Vogesite.—There are two varieties of vogesite, of which one is termed type A and the type B. The vogesite dykes of type A are red in colour and crowded with well-formed crystals of green hornblende, resembling the hornblende-porphyrites in appearance. Excellent examples are found on the shore to the north of Portavogie. They are more numerous, though narrower, than the porphyrite dykes.

Dykes of vogesite type B are green or brown in colour, and can be distinguished from type A in the field. The largest dyke is about 20 feet wide and outcrops on the headland south of Kircubbin.

Spessartites are brown or green in colour, and form intrusions of smaller size than the vogesites. They contain elongated crystals of brownish-green hornblende. A good example 3½ feet wide is found near the Butterlump Stone, south of Ballyhalbert, another typical dyke 7½ feet wide outcropping at the harbour at Ballyhalbert.

Felspar-porphyry forms red dykes which are evidently mainly felspathic. Glomeroporphyritic groups of felspar and a subordinate green mineral can be identified in the hand specimen, the ferromagnesian mineral being much less abundant than in the vogesites. Only two dykes of felspar-porphyry were found ; one 2½ feet wide occurs south of Cloghy, whilst the other, which is 16 feet wide, outcrops near the harbour wall at Ballyhalbert.

No statement can be made as to the relative age of dykes of these four types of rock since they are all parallel. Table 1 shows their size.

Dykes containing biotite and monoclinic pyroxene are of the following varieties :—

Pyroxene-minette and kersantite.
Hornblende-minette.
Pyroxene-vogesite.

Of these, pyroxene-vogesite and hornblende-minette dykes are always intruded parallel to the strike of the country rocks. In one instance, however, a dyke of the former intersects one of minette, and, consequently, the pyroxene-vogesite dykes cannot be regarded as distinctly older than those of minette. The minettes are of two varieties, which will be distinguished as type A and type B. Dykes of type A follow the strike of the sedimentary beds or take a course at right angles, whilst those of type B always cut the bedding of the country rocks at right angles and were probably the last to be intruded.

With the exception of minette type B, the varieties are indistinguishable in the field, all being dark brown or dark green in colour and characterized by a lustrous dark mica, crystals of which may measure as much as 1 cm. across. The mica flakes have a distinct parallelism due to flow. Pyroxene cannot be seen in the hand specimen.

Only three dykes of minette type B were found, but they differ greatly from the other mica types, from which they can be separated with ease in the field. Of the three dykes examined, one 2 feet and one 1 foot thick occur at Ballyhalbert harbour, whilst the third, which is 5 or 6 feet wide, outcrops south of the Coast Guard Station, Ballyhalbert. They exhibit abundant porphyritic crystals of a dark green monoclinic pyroxene, with a maximum length of 5 mm., which are embedded in a red felspathic matrix. Biotite can be detected in the hand specimens only by the glistening of its minute flakes. For the relative size and abundance of the dykes formed by these rocks see Table I.

TABLE I.—TABULAR SUMMARY OF THE THICKNESS OF DYKES OF VARIOUS TYPES OF ROCK.

Thickness.	Number of dykes of various types.								
	Hornblende Porphyrite.	Vogesite Type A.	Vogesite Type B.	Spessartite.	Felspar Porphyry.	Hornblende Minette.	Pyroxene Vogesite.	Pyroxene Minette Type A.	Pyroxene Minette Type B.
3 ft. & under	–	1	1	3	1	1	–	33	2
3 ft. to 6 ft.	–	1	3	1	–	1	–	17	–
6 ft. to 9 ft.	–	2	2	1	–	–	–	8	–
9 ft. to 12 ft.	–	4	1	–	–	–	1	2	–
12 ft. to 15 ft.	–	2	–	–	–	1	–	2	–
15 ft. to 18 ft.	–	1	–	–	1	–	–	–	–
18 ft. to 21 ft.	–	–	–	–	–	–	–	–	–
21 ft. to 24 ft.	2	–	1	–	–	–	–	–	–
24 ft. to 27 ft.	–	–	–	–	–	–	–	–	–
36 ft.	–	–	–	–	–	–	1	–	–
40 ft. to 45 ft.	2	–	–	–	–	–	–	–	–
Average size	34 ft.	9 ft.	7 ft.	4 ft.	9 ft.	7 ft.	24 ft.	4 ft.	3 ft.
Aggregate thickness	135 ft.	104 ft.	60 ft.	18 ft.	19 ft.	22 ft.	48 ft.	261 ft.	9 ft.

One multiple dyke only was found. It outcrops near the Butter-lump Stone, south of Ballyhalbert and is of pyroxene-vogesite. It forms an intrusion of the symmetrical type, the centre portion measuring 8 to 9 inches and the outer portions 4 to 5 inches in thickness. This dyke is interesting as being the only example of a dyke which is parallel to the bedding of the country rocks cutting dykes which strike at right angles, the reverse in other cases always occurring. The two narrow dykes intersected by it are minette.

(iii) XENOLITHS.

Accidental xenoliths are common and usually consist of sub-angular slate and grit fragments. In a dyke at the foot of the

dunes, north of Portavogie quay, a rounded red gneissic inclusion was observed which measured about 5 inches across.

A cognate xenolith was found in the pyroxene-vogesite dyke outcropping at the Whiskin shore. It measured 24 by 22 inches and was roughly heart-shaped, with the apex pointing upwards. In the field it could be seen to contain coarsely crystalline biotite and felspar.

(*b*) Petrology.

A study of the dykes in the field indicates the importance of the ferro-magnesian constituents, an importance which is even more apparent when the rocks are examined in thin section. Unfortunately the nomenclature of the lamprophyres is dependent on the determination of the felspars, which play the less important rôle, and it is particularly unsatisfactory in the case of the finer grained rocks where the felspars have a plumose texture and the presence of minute portions of green glass make a refractive index determination almost, if not quite, impossible.

In practically every case in which the plagioclase has been determined in the Ards lamprophyres, it has been found to be albite, whilst the patchy extinction of the potash-felspar suggests that it is anorthoclase. Thus, whichever felspar may predominate, the magma from which it crystallized was characterized by richness in soda.

For descriptive purposes the usual names have been employed, but the rocks are grouped into two classes according to the predominance of hornblende, or biotite and pyroxene, the felspars being regarded as of secondary importance.

(i) Hornblende Type.

Hornblende-Porphyrite.

The porphyrites differ from the vogesites mainly in structure. They are porphyritic, with phenocrysts of felspar and hornblende which have a tendency to parallelism due to flow. The matrix consists of minute felspar prisms and a small amount of interstitial green glass and quartz. Magnetite in irregular grains and rather broad prisms of apatite form accessories. Pseudomorphs of a chloritic, or serpentinous substance associated with magnetite and haematite, are sometimes present. They are of indefinite shape and are always surrounded by small prisms of hornblende, which have evidently been formed by reaction between the original ferro-magnesian mineral and the still fluid magma.

The felspar phenocrysts show some alteration to sericite. Plagioclase probably predominates, but orthoclase or anorthoclase is also present in considerable amount. In the matrix potash-felspar is more abundant than plagioclase. The potash-felspar usually shows the patchy extinction suggestive of anorthoclase.

Hornblende occurs in elongated prisms with the forms {110} and {010} developed in the prism zone. Simple or lamellar twinning

is frequent parallel to (100). Pleochroism is well marked: X = pale yellowish green, Y = Z = deep green, and zoning is sometimes exhibited, in which the crystals usually have a paler margin with a slightly higher extinction angle. The maximum extinction measured in the prism zone is 22° and $\gamma - \alpha = \cdot 023$ approximately.

Although the rocks appear porphyritic, close examination reveals the fact that there are all gradations in the size of the hornblende and felspar crystals down to that characteristic of the groundmass. This structure has been shown by Beger [1] to characterize the lamprophyres from Lausitz, Saxony.

With regard to the order of crystallization, hornblende is occasionally enclosed in the felspar phenocrysts, whilst the larger crystals of hornblende are frequently riddled with inclusions of the matrix When the hornblende is viewed in cross section, these inclusions sometimes appear in a definite zone, so that the crystal has an isolated outer shell. Some of the hornblende prisms have felspar crystals clinging to them in the prism zone, whilst hornblende is at times arranged around the largest felspars in a manner indicative of flow. Thus crystallization of the component minerals appears to have gone on simultaneously.

A specimen (No. 213) [2] from the dyke exposed in the sand on the shore south of Portavogie was selected for analysis, the analysis, norm and mode being as follows :—

Analysis.[3]		Norm.		Mode (percentage volume).	
SiO_2	55·40	quartz	6·78	hornblende	29·2
Al_2O_3	16·22	orthoclase	12·79	felspar phenocrysts	12·6
Fe_2O_3	1·71	albite	35·63	matrix, mainly felspar	
FeO	3·72	anorthite	13·34	with a little quartz	
MgO	5·45	corundum	2·04	and green glass	58·2
CaO	5·40	hypersthene	17·82		
Na_2O	4·20	magnetite	2·55		
K_2O	2·15	ilmenite	·76		
H_2O +	2·4	iron pyrites	·36		
H_2O −	·30	apatite	·34		
CO_2	2·00	calcite	4·5		
TiO_2	·42				
P_2O_5	·24				
S	·22				
MnO	Traces				
	99·83				

Symbol II.(4)5.2″.4.

Specific gravity = 2·768 ± ·001 at 4° C.

Although the modal and normative minerals are different, yet some idea can be gained as to the nature of the potash-felspar pre-

[1] P. J. Beger, " Beiträge zur Kenntnis der Kalkalkalireihe der Lamprophyre im Gebiete des Lausitzer Granit-lakkolithen ": *Neues Jahrb.*, B–B, xl, 1916, 583.

[2] These numbers refer to the specimens and thin sections in the collection at Bedford College, Regent's Park, London, N.W. 1.

[3] The chemical analyses were made by Mr. W. H. Herdsman.

sent in the rock. Hornblende forms 29 per cent of the porphyrite by volume and is estimated to constitute 35 per cent by weight, any error being in the nature of an over-estimate. As a basis for calculation, the hornblende is assumed to be similar in composition to that from Edenville,[1] the analysis of which has been recast as a norm as follows :—

Analysis.		Norm.	
SiO_2	41·99	orthoclase	6·12
Al_2O_3	11·62	albite	3·14
Fe_2O_3	2·67	nepheline	9·66
FeO	14·32	anorthite	17·51
MgO	11·17	diopside	27·58
CaO	11·52	olivine	26·32
Na_2O	2·49	magnetite	3·94
K_2O	·98	ilmenite	2·89
H_2O	·61	fluorite	1·64
TiO_2	1·46		
F_2	·80		
MnO	·25		
Loss at 110°	·08		
	99·96		
$O = F_2$	·33		
	99·63		

The norm indicates the amount in grams of normative minerals present in 100 grams of hornblende, so that 35 grams of hornblende would contain :—

orthoclase	2·14 grams
albite	1·1 „
nepheline	3·38 „

Recalculating the albite in the norm of the porphyrite so as to include 3·38 parts of nepheline, the partial norm of the rock becomes :—

orthoclase	12·79 grams
albite	29·34 „
nepheline	3·38 „

Then subtracting the normative potash- and soda-bearing minerals present in 35 parts of hornblende from the norm of the porphyrite, the total felspar of the rock is found to contain albite and orthoclase in the ratio 28 : 11. If one-third of the felspar by weight is albite, which is a distinct over-estimate, then the ratio of albite to orthoclase in the potash-felspar is approximately 15 : 11 and it has the composition of anorthoclase. Making up the 35 parts of hornblende with hypersthene, magnetite, ilmenite and anorthite from the norm of the rock, together with the proportions of orthoclase, albite and nepheline shown above, the composition of the anorthoclase is found to approach $Ab_{13}Or_{11}An_6$. It is not

[1] W. E. Ford, "Optical Study of the Amphiboles": *Amer. Jour. Sci.*, xxxvii, 1914, 181.

Fig 1.

Fig 2.

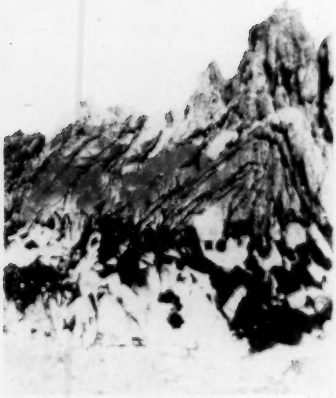

Fig 3.

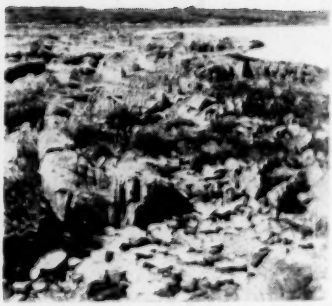

Fig 4.

CRUSHED LAMPROPHYRE DYKES, ARDS PENINSULA.

To face p. 111.]

suggested that this represents the composition of the potash-felspar; it rather indicates the lowest ratio of albite to orthoclase and the highest ratio of anorthite to orthoclase it is likely to contain.

Anorthoclase, as defined by Alling,[1] may contain as little as 30 per cent albite, so that, if the potash-felspar included 4·7 parts of albite only to 11 of orthoclase, it would still be anorthoclase. In that case, calculating one-third of the felspar as albite as before, the total felspar in the porphyrite would contain albite and orthoclase in the ratio of 12·6 : 11. If the felspar includes only 12·6 per cent of albite, then the hornblende must contain 7·7 per cent of soda. That is, the potash-felspar must have the composition of anorthoclase, provided the hornblende does not contain a higher proportion of soda to potash than 7·7 : ·98, which ratio is only exceeded in the soda amphiboles, normal hornblende rarely containing more than 3 per cent soda.

Actually the ratio of albite to orthoclase in the total felspar could not be so low as 12·6 : 11, since the quantity of normative anorthite present in the porphyrite is not sufficient to make up, with 12·6 grams of albite and 11 grams of orthoclase, the total weight of modal felspar.

This then constitutes proof that the potash-felspar in the porphyrites has the composition of anorthoclase.

EXPLANATION OF PLATE VI.

CRUSHED LAMPROPHYRE DYKES, ARDS PENINSULA.

FIG.

1.—A schistose minette dyke (No. 109) at Kearney Point intruded parallel to the bedding of the country rocks.

2.—A minette dyke (No. 115) at Kearney Point truncating folds in the Silurian slates and grits.

3.—A minette dyke (No. 144) in the bay north of Quintin Castle. The dyke, which is partly covered with seaweed, truncates a fold in the slates.

4.—A minette dyke (No. 36) at Old Man's Head which is cleaved but not foliated. The position of the dyke, which is intruded parallel to the bedding of the country rocks, is marked by the hammer.

(*To be continued.*)

Some Coastal Features of North Cardiganshire.

(PLATE VII.)

By JOHN CHALLINOR, M.A., F.G.S.

THE Cardiganshire coast shows various geological features of considerable interest. The present paper deals chiefly with the character and evolution of the coastal slopes and cliffs in the north of the county, between Borth and Aberayron.

As a preliminary, certain theoretical questions may be discussed very briefly.

[1] H. L. Alling, "The Mineralography of the Feldspars": *Jour. Geol.*, xxix, 1921, 233.

The production and evolution of shore-profiles has been fully expounded in numerous treatises,[1] but little attention seems to have been paid to what appears to be an important part and aspect of the coastal profile ; the part above the top of the cliff, and the profile as a whole from the base of the cliff to an indefinite (and varying) distance inland. The only discussion, known to the writer, of the subaerial erosion curves produced across a coast is that in Arber's work on North Devon.[2]

We may consider first the rivers and streams. Allowing the diagram (Fig. 1) to represent various cases, let us first take the case of a relatively large river R1 (imagining the profile to be drawn through a part of the land along which this river is flowing). After a certain time the longitudinal profile of the river may be taken

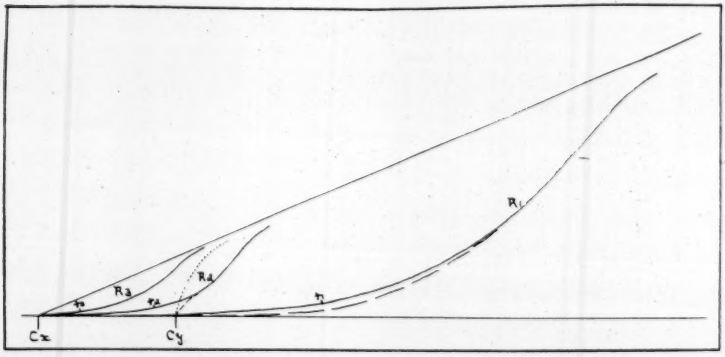

FIG. 1.—Diagram of theoretical longitudinal stream-profiles at a coast. Cx, position of coastline at time of initiation of streams. Streams supposed to be initiated after completion of earth-movement ; no further earth-movement occurring. R1, R2, R3, three streams. Continuous lines show theoretical profiles at the end of some period supposing the coastline to have remained stationary ; *r*1, *r*2, *r*3, corresponding points of flexure. Broken lines show theoretical profiles under conditions of movement of the coastline by marine erosion, from C*x* to C*y*, during the period (— — —, R1 ; - - -, R2 ; . . . . . , R3).

to have reached some such form as shown. Although there are no " kinks " in a river's ideal profile, except those specially produced by known local factors, there is an important portion of the profile where the flattened part under the dominance of base-level passes into the upper concave or irregular part. This may be termed here the *reach of flexure*. There is no abrupt change from the one part of the profile to the other, but we may select a point which, although its exact position is arbitrary, may be taken to mark the

[1] e.g. D. W. Johnson, *Shore Processes and Shoreline Development*, 1919.
[2] E. A. N. Arber, *The Coast Scenery of North Devon*, 1911.

change : this may similarly be termed the *point of flexure*. Suppose *r*1 to represent this point for this river. During the time taken for the river to develop its profile to the state shown, we may imagine the sea, and with it the point of base-level, to have advanced from *Cx* to *Cy*. This advance will have been proceeding during the development of the river's profile. The significant fact is that the point *r*1 has moved farther (i.e. faster) inland than the point C. This means that the river has been able—has, in fact, been forced—to produce a flattened profile in its lower reaches and all the time to maintain it. The effect of the marine advance is merely a shortening of the flattened part of the profile by the amount of this advance, though this shortening is to some extent compensated by a slight hastening of the advance upstream of the point of flexure. If the sea advanced in sudden stages the effect would be a series of migrating and fading convexities.

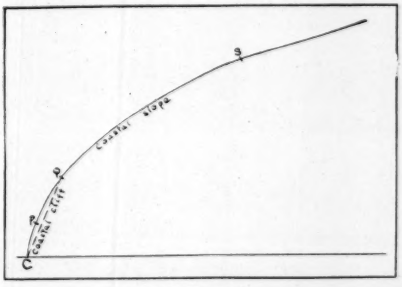

FIG. 2.—Diagram of theoretical profile of a coast where subaerial erosion is not concentrated in a stream. The coastline C is moving inland by marine erosion, and keeping constant level. Continuous line shows the profile produced supposing the rock to be stable at all angles; broken line, cliff produced if the limiting stable angle of rest be that made by the tangent at the point P (on the original curve) with the horizontal. The cliff has a uniform slope at this angle and passes abruptly into the coastal slope at Q. The coastal slope merges gradually into the hinterland, which beyond the point S is as yet unaffected by coastal erosion.

If now we examine the case of a smaller river R2, in which the point *r*2 is the point of flexure, we find that the marine advance is faster than the potential advance of this point. Thus this river never produces a flattened profile near base-level, and the form of the river when the sea has reached *Cy* is shown by the broken line. This river is really a hanging stream, though not very markedly so and with a tendency to produce a concave middle part in its profile.

The stream R3 is still smaller. It could have pushed its point of flexure only so far as *r*3 while the sea advanced to *Cy*. It is a very pronounced hanging stream, and its profile is entirely convex Such a stream advances as a whole landwards as the coast advances.

Suppose the section to be taken across a portion of the coastal belt where there is no regular stream; this would be the most likely section if taken at random, and may be considered typical. Erosion will be in the form of weathering and removal of the weathered material by landslips, surface-creep or gravity acting alone. The theoretical form of the profile (or, at least, the present writer's conception of it) is shown in Fig. 2, and is merely the "hanging profile" carried further. The lowest part will be vertical. Most rock-formations become unstable if eroded to form slopes greater than a certain limiting slope depending on the local character of the formation. Suppose this limiting angle to be that made by the tangent at the point p with the horizontal, then all that part of the slope below p is unstable and the profile will become cliffed.

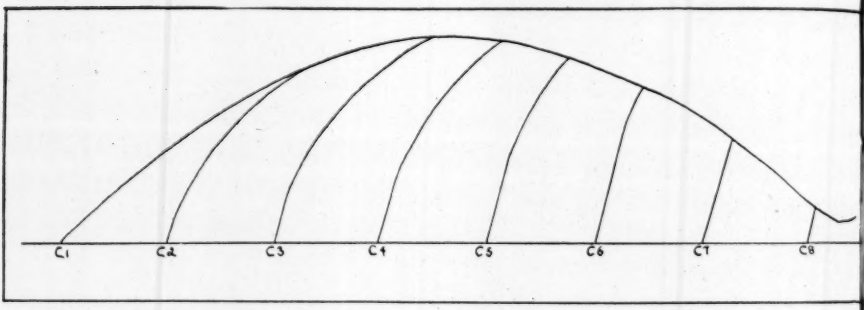

FIG. 3.—Diagram of theoretical profiles of a coast; the coastline advancing across a hill. C1–C8, positions of the coastline after successive (but not necessarily equal) periods of time. The form of the original hill is considered to be unmodified by any erosion other than that induced by marine erosion. In this figure, as in Figs. 1–2, the section is taken at right angles to the coastline, and the likely vertical scale is exaggerated.

FIG. 4.—Sketch-map of the coast of North Cardiganshire. To show the coastline, chief rivers, and general relief, the main facts of the geology of the coastline, and the positions of the profiles shown in Fig. 5. Also the chief towns and villages. Note on the mapping of the boulder-clay: With his kind permission I have made use of some of Mr. K. E. Williams' unpublished lines mapped on the 6 in. scale; these show the position of the immediately pre-glacial coastline. The coastal drift is shown only where it reaches the base of the cliffs; the drift that covers much of the inland area is not shown. (See page 115.)

The part above the cliff, where the profile is steepened as a result of marine erosion, may be called here the *coastal slope*.

If we examine the effect of a coastline advancing across a hill, it appears that, even if there is as much slope landwards as seawards, the cliff will be backed by a rising slope over the greater part of its line of travel. This may explain why along most coasts, as along the North Cardiganshire coast, cliffs are usually backed by rising ground. It seems to the present writer that this fact cannot

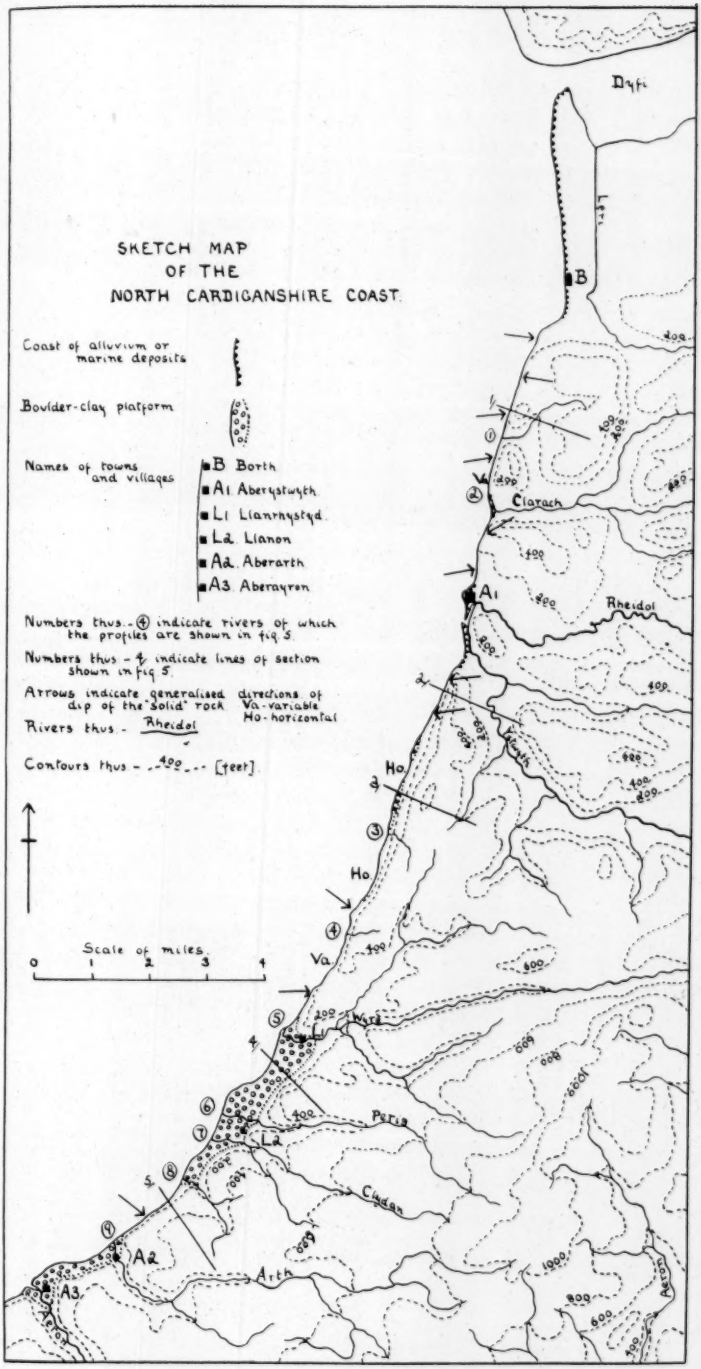

FIG. 4.—Sketch-map of the coast of North Cardiganshire.

be used as an indication of a youthful coast, as has been done by Johnson.[1] Fig. 3 explains this idea.

We may now proceed to consider the actual coastal slopes and cliffs in the region with which we are particularly concerned.

The Cardiganshire coast begins, in the north, on the south side of the Dyfi (Dovey) Estuary (see the sketch-map, Fig. 4), and for the first 3½ miles it is formed by deposition, being composed of sand-dunes near the mouth of the estuary and southwards beyond Ynyslas, and of a long straight shingle-ridge in the neighbourhood of Borth. It will be sufficient here merely to mention this remarkable northernmost end of the Cardiganshire coast and the great silted-up and overgrown area of Borth Bog behind it.[2]

South of Borth we enter on the rocky coast, with steep cliffs and slopes rising into the plateau where the higher ground reaches about 450 feet on the average. The " solid " rocks of the whole of the coast considered in this paper belong to the Aberystwyth Grits formation of the Silurian. At first, the coastline cuts obliquely into the margin of this plateau, but after about a mile the coastal slopes and cliffs are carved directly out of it. At the outstanding rock of Craig y Delyn, or the " Harp Rock " (1½ miles south-west of Borth), and for about half a mile to the south, the cliffs are very high and steep, reaching to the top of the plateau ; being produced in rocks dipping at a high angle to the west (Pl. VII, Fig. 1). This structure dominates the coastal scenery, the huge grit-slabs plunging seawards to form the cliff-faces which are broken up by joints and plastered with scree. In his book on " Mountain Ranges ", Mellard Reade [3] gives a picture of this locality and also illustrates the rock-structures and scenery of other parts of the coast between Borth and Llanrhystyd. An interesting detail of wave-erosion may be seen at the foot of the rock ; it is one that occurs also at several other places along the coast. This is a wave-cut pothole, a basin initiated, enlarged, and smoothed by the swirling round in it of beach-pebbles (Pl. VII, Fig. 2). The writer has not seen any records of similar features in Britain, nor do they appear to be mentioned in the text-books. They have, however, been described from America.[4]

Further south the dip changes to a direction E.N.E., being thus landwards although rather obliquely so. The cliffs are no longer dominated by individual bedding-surfaces ; they are even steeper than those to the north, but not so high and the coastal slope is

[1] D. W. Johnson, *The New England–Acadian Shoreline*, 1925, 192, 334.

[2] This region has been described by Professor O. T. Jones in R. H. Yapp, D. Johns, and O. T. Jones, " The Salt Marshes of the Dovey Estuary " : *Jour. of Ecology*, iv, 1916, 27–34.

[3] T. Mellard Reade, *The Origin of Mountain Ranges*, 1886, 184–90, pls. xxviii–xxx.

[4] A. C. Swinnerton, " Observations on some Details of Wave Erosion : Wave Furrows and Shore Potholes " : *Jour. Geol.*, xxxv, 1927, 171–9.

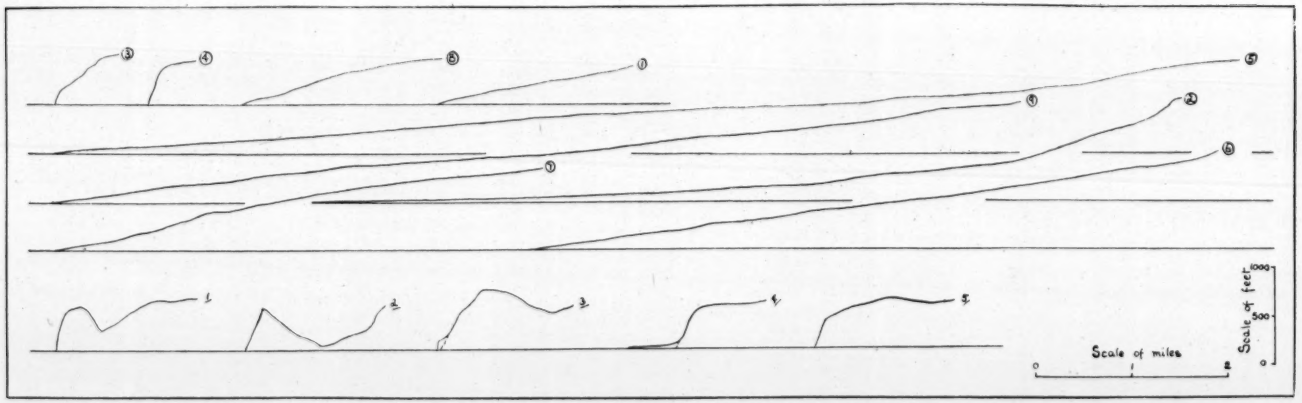

FIG. 5.—Coastal profiles, North Cardiganshire. Above: Longitudinal profiles of the chief rivers of the North Cardiganshire coast, except the four largest—the Leri, Rheidol, Ystwyth, and Aeron. These four, with the Clarach (2), are the five rivers of "R 1 type" along this coast. Below: Cross-section profiles of the coast along various lines. The rivers and the lines of section are shown in Fig. 4. All these profiles were drawn from the 1 in. Ordnance Survey map showing contours at 50 ft. vertical intervals.

well-marked (Fig. 5, 1 ; Pl. VII, Fig. 3). At Wallog the plateau is interrupted by a valley. The stream here is of the general type, discussed above, of R2 tending to R3 (Fig. 5, (1)). This valley contains much glacial material, and south of the old limekiln even the base of the cliffs is formed of it and the characteristic erosion-features are well seen on a small scale ; but for the most part here, as in the other cases where drift-filled valleys reach the sea, it forms a veneer, and the cliffs show sections with glacial material on the top and solid rock below. Beyond the limit of the valley-drift we have cliffs and slopes essentially in solid rock until Clarach Bay is reached. The structures are complicated and the dip does not keep constant either in amount or direction for any considerable distance. The cliffs vary in steepness and height, and the coastal slope here is not very steep.

Clarach Bay is formed by a wide valley. But the stream in it is a small one, although it has a well-developed flattened part for a considerable distance from its mouth (Fig. 5, (2)). It is evidently a "misfit", and the anomaly is probably one of those drainage modifications which seem to have been brought about in this region as a result of the Ice Age. After crossing the small shingle banks and sand-dunes (which have incidentally diverted the mouth of the Clarach stream to the north side of its valley, as is the tendency in the case of all these streams which flow into the sea along the Cardiganshire coast) [1] the mile of rocky coast separating this bay from Aberystwyth is reached (Pl. VII, Fig. 4). The cliffs are steep and high, passing upwards into well-marked coastal slopes, though they vary in steepness and the height tends to increase towards Aberystwyth. There is a general approximation to a north-and-south strike along this stretch of coast, but the structures are of great variety (admirably displayed in section and plan in the cliffs and on the shore) and do not control the form of the cliffs as a whole, though there are excellent examples of the local control by structures of the minor effects of marine erosion.

At Aberystwyth the Rheidol valley reaches the sea and just south of the town, separated by the hill of Pen Dinas, the Ystwyth valley does the same. These are large valleys of the R1 type.

The rocky coast is resumed in the cliffs of Allt Wen[2] (Pl. VII, Fig. 5), and for a mile and a half these cliffs are very uniform. The structure of the rocks is regular, the strike being approximately north-and-south and the dip constantly to the west (seawards) at an angle of 30°. This dip governs the cliff-slope which rises at a more or less constant angle of 30° right up to the top ; at the base the cliff is in most places steepened by horizontal wave-cutting. There is no coastal slope, for a sharp crest forms the top of the cliff.

[1] O. T. Jones, "The Physical Features of Central Wales" : *National Union of Teachers Souvenir*, Aberystwyth Conference, 1911, 40-1.
[2] *Hor. Sect. Geol. Surv.*, Sheet 6.

Such a coast, of which an example has already been seen at Craig y Delyn, may perhaps be called a " coastal scarp ", though if such a term be used it should be noted that the scarp-slope is essentially (at least in the present variety) a steep dip-slope. This coastal scarp (Fig. 5, 2) is obviously advancing into the land behind it, which is here sloping eastward to the valley of the Ystwyth. The scarp as it advances is thus becoming lower.

Along the crest of the scarp the land is seen to be slipping-away seawards, and all down the face of the cliff landslips are apparent. In some places along the top this breaking and slipping-away is very clearly seen to be along joint-surfaces and bedding-surfaces, gaping clefts being produced. The Aberystwyth Grits are everywhere well-bedded and well-jointed, but are particularly so in this neighbourhood. The rocks are torn apart along the strike-joint-planes, which may be seen in various degrees of strain before actually producing a fissure ; and blocks of rock move seawards, breaking along the dip-joint-planes and sliding over the bedding-planes. At the foot of the cliffs, where the oversteepening occurs, the breaking up of the rocks along these surfaces is also seen very well (Pl. VII, Fig. 6).

This regular coast passes southward into a different type, characterized by a platform of glacial material. This deposit along the Cardiganshire coast has been described by K. E. Williams.[1] For about two miles the sea cliffs are carved in boulder-clay ; although along part of this stretch the solid rock protrudes underneath and forms the lower part of the cliffs. Cliffs formed entirely in boulder-clay are splendidly displayed west of Cwm-ceirw farm ; they are about 100 feet high and are nearly vertical, and undercut in places at the base ; they are greatly gullied and the ridges between the gullies are carved into mounds and pillars. At the top, the cliffs pass with clean abruptness into the regular and gently-sloping surface of the platform which itself soon merges into the true coastal slope (Fig. 5, 3). Any pre-glacial cliffs are either smothered in the clay or have been obliterated by the smoothing action of subaerial erosion, and grown-over.

Just north of Monk's Cave a good example of a small hanging stream of R3 type plunges down the coastal slope (Fig. 5, (3)), and from here to the projecting rock of Careg Ti-pw near Llanrhystyd, a distance of about 3 miles, the coast is carved in " solid " rock with steep cliffs and steep high coastal slopes (Pl. VII, Fig. 7). The bedding tends towards the horizontal and the cliffs approach the vertical ; the whole coast is very wild and in places the base of the cliffs is inaccessible even at lowest water. Hanging valleys occur (Fig. 5, (4)).

West of Llanrhystyd, and stretching for some 3½ miles southwestward along the coast, is a very pronounced platform of boulder-

[1] K. E. Williams, " The Glacial Drifts of Western Cardiganshire " : Geol. Mag., LXIV, 1927, 205–27.

clay. It is some half a mile wide and forms a coastal strip sloping very gradually from about 100 feet above sea-level to the sea. Parts of the shore are backed by low cliffs cut into it, parts by shingle-deposits. The pre-glacial coastal slope is well seen (Fig. 5, 4).

At Llanrhystyd several rivers unite and flow as one stream across the platform to the sea. The longest of these is the Wyre (Fig. 5 (5)), most probably carved along a great belt of faulting.[1] However, it does not show a flattened part near base-level and this river, as also the two that flow out near Llanon (the Afon Peris, Fig. 5 (6), and the Afon Clydan, Fig. 5, (7)) and the Afon Arth (Fig. 5, (9)), are of the R2 type. The stream that flows through Morfa (Fig. 5, (8)) is, like that at Wallog, of type intermediate between R2 and R3.

Between Morfa and Aber-Arth the coast is cliffed in the "solid" rock (Fig. 5, 5),[2] but between Aber-Arth and Aberayron there is again a platform of boulder-clay. Several remarkable "earth pillars" have been eroded out of the boulder-clay which tops the rocky cliff north-east of Aber-Arth (Pl. VII, Fig. 8).

The 1½ miles of coast between Aber-Arth and Aberayron is formed by another conspicuous remnant of the boulder-clay platform, while beyond the town are resumed the rocky cliffs and slopes typical of the Cardiganshire coast as a whole.

DESCRIPTION OF PLATE VII.

FIG.

1.—Craig y Delyn. View looking northwards. The cliffs here are high and steep, and are produced in rocks dipping at a high angle seawards. The structure is well-seen on the side of the rock, Craig y Delyn; the bedding surfaces are slightly curved and in one place are crossed by something in the nature of a small thrust. Near the shore the dip is less steep and ceases to govern the form of the seaward rock-face which is here nearly vertical. Large fragments from the nearer cliff-face are seen on the shore in the foreground.

2.—Wave-cut Pothole, Craig y Delyn. The smooth basin-shaped hollow is being scooped out by coarse shingle on a sloping surface washed by the waves.

3.—Coast at Wallog. The cliffs immediately north of the little inlet (the position of which is marked by the house) are very steep and largely in boulder-clay. Further north, the profile of the coast shows a moderately steep cliff (in solid rock) passing into the coastal slope above.

4.—Wave-cut Platform, south of Clarach Bay. The bedding of the rocks is etched out by wave-action. In the distance across the bay is a cliff formed in beds dipping landwards, and the coastal slope behind it.

5.—South Bay and Allt Wen Cliffs. A view across the South Bay (backed by a large shingle-ridge) with the Allt Wen cliffs in the background. At the top of the cliffs, which conform to the regular seawards dip of the rocks, the slope changes abruptly landwards.

6.—Rectangular Blocks, south of Aberystwyth. This photograph, taken at a point about one mile south of Allt Wen, shows the breaking up of the rock.

[1] O. T. Jones, "The Geological Structure of Central Wales": *Quart. Jour. Geol. Soc.*, lxviii, 1912, 343.

[2] *Hor. Sect. Geol. Surv.*, Sheet 4.

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8

Coastal Features of North Cardiganshire.

[To face p. 120.

FIG.

along joints at the cliff-base, into rectangular tabular blocks, which slip along the bedding on to the shore. Scree from the higher parts of the cliff is also seen.

7.—Cliffs and Slopes, south of Monk's Cave. The cliffs are steep and pass upward into steep, high coastal slopes. The bedding is at a low angle. In the middle distance a stack may be seen, and, beyond, the boulder-clay cliffs near Cwm-ceirw.

8.—Earth Pillar, north-east of Aber-Arth. The pillar is formed in boulder-clay which here plasters the upper part of the cliff. In the distance is the boulder-clay platform near Llanrhystyd.

The Tertiary Igneous Geology of the British Isles: An Essay-Review.

"The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban," by E. B. Bailey and others. *Mem. Geol. Survey*, 1924.
"The Geology of Arran," by G. W. Tyrrell. *Mem. Geol. Survey*, 1928.
"The Geology of Ardnamurchan, North-west Mull, and Coll," by J. E. Richey and H. H. Thomas. *Mem. Geol. Survey*, 1930.
"The Structural Relations of the Mourne Granites," by J. E. Richey, *Quart. Journ. Geol. Soc.*, lxxxiii, 1927, 653.
"The Major Intrusions of South-eastern Iceland," by L. Hawkes and others, ibid., lxxxiv, 1928, 505.
"The Geology of the Shiant Isles," by F. Walker, ibid., lxxxvi, 1930, 355.
H. H. Thomas, *Pres. Add.* Section C. Brit. Ass., Leeds, 1927.

OWING to various unlucky circumstances the *Geological Survey Memoirs* on Mull and Arran were not reviewed in the GEOLOGICAL MAGAZINE at the time of their publication. The recent appearance of the third member of this great trilogy, on Ardnamurchan, has suggested that the time is now opportune for a general discussion of the whole subject treated in these *Memoirs* and in certain other publications of cognate nature.

Even from the days of Hutton and Faujas de Saint Fond, Macculloch, Ami Boué, de Saussure, von Oeynhausen and von Dechen, the igneous geology of the Western Isles has been prominent in geological literature, while it bulked still more largely in the days of Judd and Geikie, having then become a matter of controversy. The battle has raged mainly between the claims of volcanoes of the Hawaiian type and fissure eruptions as the source of the great plateau basalts: none of the combatants realized fully the complexity of the problem in which they were engaged, as is rendered fully apparent in the various publications listed above. It is now quite clear that no single man in an ordinary lifetime could have been competent to solve it, and we can only offer a tribute of admiration to the magnitude of the results achieved by these pioneers.

The modern period may be said to begin with the appearance in 1904 of Dr. Harker's epoch-making memoir, *The Tertiary Igneous Rocks of Skye*, followed not long after by that on the Small Isles, 1908. In these a great step in advance is made, while most of the later developments are foreshadowed. The normal succession of

volcanic, plutonic, and hypabyssal, with the differentiation-sequences, are clearly laid down, while composite intrusions and hybridization are described. The migration of centres of eruption in the broad sense also receives adequate treatment, and the "inclined sheets" of Skye are identical with the "cone sheets" of the later memoirs. The recognition of the cauldron-subsidence of Glencoe by Messrs. Clough, Maufe, and Bailey, in 1909, and the mapping of the dykes of that area introduced new and fruitful conceptions into British igneous geology.

At first sight the most spectacular problem of all is the origin of the vast sheets of plateau-basalt which extend from the neighbourhood of Belfast, at intervals, to the islands of the Arctic, and, apparently, into Siberia. Although the special characters of Icelandic volcanicity had long been known, Prof. Judd explained the British occurrences as due to volcanoes of the Hawaiian type. The visit of Sir Archibald Geikie to the Snake River Plains in Western America led him on the other hand to attribute them to fissure-eruptions, a term which hardly needs definition here, and for long this explanation has held the field. But the recent intensive work in Scotland has again raised doubts. In the first place we have to consider the fact made abundantly clear, that the dykes, hitherto supposed to be feeders of these vast lava-fields, almost the earliest of the eruptions, are of all sorts of ages, and often cut the later members of the intrusions; secondly, that they are by no means evenly distributed, but arranged in "swarms" which point to localized centres of intrusion and explosion; and, thirdly, that it is categorically stated in one of these memoirs (Ardnamurchan, p. 52) that no dyke has ever definitely been traced into a basalt flow. This is a most important point, and the statement was no doubt made with a due sense of responsibility.

In view of this, we are inevitably driven to explore other possibilities. As a starting-point, we may quote the remark of Prof. Judd that the Island of Hawaii is about the same size as the basalt plateau of Antrim. This shows the advantage of thinking to scale in geological problems. In most of our atlases Hawaii is a mere speck. It is about 70 miles across, and extends as far again below sea-level.

It may, perhaps, be useful to give a few more figures. From Carlingford to the north point of Skye is about 250 miles; from the north point of Skye to the Färoer is nearly 300 miles; from the Färoer to Iceland, rather less, say 250 miles; from Iceland to Jan Mayen about 350 miles. That is to say, the intervals between the existing basalt areas are rather greater than the lengths of the areas themselves. Furthermore the N.–S. linear elongation is most marked, suggesting a relation to the eastern margin of the Atlantic basin. In discussing the possible former extension of the plateau-basalts much stress has always been laid on their "enormous" thickness. Now it does not appear that anything

greater than about 3,000 feet can be proved in Britain. North of Skye there is no trace of them on the mainland of Scotland or on the Island of Lewis, and there is nothing to show that their east–west extension was ever very great. The Northumberland and Cleveland dykes can no longer be accepted as proving a former extension of plateau basalts into northern England, still less the Staffordshire post-Triassic dykes. Comparing the maximum thickness of 3,000 feet in Mull with the distances involved, we see that a very flat gradient of thinning would bring the flows to an end at a quite small distance from the last visible outcrop: there is no sign of them on Jura and Islay, just halfway between Mull and Antrim. Subsidence can account for the absence of basalts between the Färoer and Iceland, but it cannot explain the fact that Jura and Islay consist of Pre-Cambrian rocks. Any attempt to prove a once continuous basalt field from Iceland to Ireland seems to lead to inconsistent results, when based on earth movements: the invocation of an elaborate system of differential denudation depending on unknown controlling factors, does not appear to be any more satisfactory. The high elevation of so vast a mass of heavy rock as Iceland presents a difficult problem in isostasy, and Dr. Hawkes seems to have realized this in his not very satisfactory argument as to the former continuity of the various basalt fields (Iceland paper, p. 534). Frankly, I do not understand his idea of the heavy basalt block compensated by light material below. It sounds like toast on a poached egg. Apart from these somewhat theoretical considerations, there is the logic of facts. It is quite certain that in Skye, Ardnamurchan, Mull, and Arran there were vast eruptive centres, and still more cogently, the dykes, the supposed feeders of the wide-spread fissure-eruptions, most markedly and definitely converge in swarms towards these same centres. Professor Bailey, writing in the introductory chapter of the Mull memoir (p. 4), has a somewhat ambiguous remark in this connection: "He thinks that this centre has repeatedly served as a focus of fissure-eruptions"; but he is doubtful whether the lavas still spared by erosion are not, in the main, the products of a central volcano, an idea always linked with the name of Professor Judd". Now surely in the pure and uncontaminated doctrine of fissure-eruptions, there is no focus? Professor Bailey cannot have it both ways. Even Sir A. Geikie admitted that the distribution of the dykes was not uniform.

At any rate it is interesting to modern geologists to assist at the reconstruction of the giant volcanoes of western Scotland erected by Professor Judd, which were so conclusively demolished by Sir Archibald Geikie. This is a striking example of the swing of the pendulum, a phenomenon which has been so conspicuous a feature of recent geological work in many departments of the science, and, it must be confessed, is somewhat depressing to those of advancing years.

It is notorious that the dominant trend of the great majority of the Tertiary dykes, even when allowance is made for their convergence in swarms, is N.W.–S.E. For this there must, of course, be a reason, and this reason is easily found in the similar strike of the earliest of all the Scottish formations—the Lewisian, a structural feature which makes itself manifest in many ways even among the later stratigraphical systems of the English Midlands and, therefore, probably underlies the whole of the British Isles north of the Thames and Bristol Channel, and may even be traceable in Cornwall. The influence of this ancient N.W.–S.E. trend appears to be unescapable during the less violent earth-movements of later ages, although it was overridden by the cataclysmic Caledonian and Armorican orogenies in their respective areas.

After all these generalities it may be well to descend to a discussion of certain particular points raised in the memoirs and papers now under review. It may perhaps be suggested with all deference that the subject would have been made easier for the general reader if the three Survey memoirs had appeared in a different order. The Mull memoir, which deals with the most complicated area, was published first. The case of Ardnamurchan, which is in most respects essentially similar, is in some ways easier to comprehend, while both throw much light on the special problems of Arran, which are difficult to interpret without the detailed discussions of the other two. Furthermore, the whole subject has been much illuminated by the Presidential Address of Dr. Thomas to Section C of the British Association at Leeds in 1927, and the closely similar chapter in the Ardnamurchan memoir.

In the Mull memoir one of the most important points raised is the discrimination of three different basaltic magmas, the plateau-basalt magma, and the porphyritic and non-porphyritic central types. It is to be feared that in the minds of some a certain amount of confusion of thought has been introduced by these terms. A footnote on p. 68 of the Ardnamurchan memoir seems to refer obliquely to this point by its clear and categorical explanation that lavas of "Central Magma-Type" are not necessarily to be regarded as products of *central* volcanoes, but that the term merely applies to olivine-poor basalts found in the *middle* of the Island of Mull. It is scarcely necessary even to allude to the great use that Dr. Bowen has made of the characters of the various Mull magmas in his book *The Evolution of the Igneous Rocks*. While the question of differentiation is in the forefront, it may just be mentioned that Dr. Walker has brought forward a particularly clear case of the formation of a picrite by crystal sinking at the base of a huge crinanite sill in the Shiant Islands. On the other hand the account in the Mull memoir of the supposed occurrence of a similar process in certain steeply inclined intrusions is quite singularly unconvincing. The case selected as the type example, the Glen More ring dyke (p. 323), reads like an excellent description of a case of hybridization,

and might almost have been written by Dr. Harker about Marsco.

In both Mull and Ardnamurchan the most striking feature is the extraordinary complexity of the focal centres: in both cases their innate complexity of extrusion, explosion, and intrusion is further complicated by shifting of the centres. (The relations in Arran will be dealt with presently.) In Skye also there was a migration, but of a simpler type. The reading of the story in the field in Mull was a matter of extraordinary difficulty, and the exposition of it in the memoir is not always easy to grasp.

In Arran there are no undisturbed plateau-basalts, but from fragments preserved in later pyroclastic accumulations there is every reason to believe that such once extended to and perhaps all over the island.

The two most important features of the igneous geology of Arran are the great almost circular granite mass of the northern part of the island (Goatfell area), and the ring complex of the central region. The northern usually coarse-grained granite encloses finer-grained patches, apparently somewhat later in date, much as does the Land's End granite in Cornwall, and it is also cut by various dykes. Concerning this intrusion, the most interesting point at the present time is that raised by Prof. Bailey in his highly suggestive comparison with the Vredefort mass. The amount of metamorphism induced by this large mass in N. Arran (8 by 7 miles), appears to be surprisingly small, and John Smith long ago suggested from a study of its slabbiness that it had been pushed up in at least a partly solid form. Now, if there is indeed an analogy to Vredefort, the possibility of this must be taken into account.

The ring complex, though much less complicated and lacking certain features, e.g. there is no reference in the memoir to cone-sheets, presents a close analogy to the centres of Mull, Ardnamurchan, and Skye; ring-dykes and screens are quite clearly present, as well as explosion-breccias (often spoken of as agglomerates, a usage to which Dr. Tyrrell raises a well-founded objection, since some of them seem to have been formed underground).

A comparison of the northern granite and the central ring-complex leads Dr. Tyrrell to the significant conclusion that the former type may simply represent a very much more deeply eroded example of the latter. This idea seems to be quite in accordance with Mr. E. M. Anderson's theoretical discussion of the origin of cone-sheets and ring-dykes in the Mull memoir (p. 12).

With regard to the actual forms of intrusions in such areas, which is about the most important question raised by all this recent work, it seems that cone-sheets and ring-dykes have come to stay. No doubt they will presently be found in other districts, possibly including some where they do not exist. A more difficult problem is the real form of some of the greater intrusions. In this regard Mr. Richey's work in Ireland is certainly important.

It appears to be consistent with Dr. Brammall's results on Dartmoor, for example, which are founded on the work of Cloos, but the granites of western Cornwall, whose form is so well known owing to mining work, do not seem to conform at all well to such explanations. These are certainly not plugs with steep sides, but cupolas on a bathylith, with underground connections at a small depth. Again, Dr. Harker's interpretation of the Cuillin gabbro as a cedar-tree laccolith seems to be beyond question. Evidently all cannot be referred to one type, although varying degrees of denudation may have a good deal to say on this aspect of the case.

In conclusion it only remains for me, both as writer and as editor, to apologize for the inordinate length of this effusion, which I believe, however, is justified by the intrinsic importance of the subject.

R. H. Rastall.

A Contribution to the Correlation of the Dalradian Rocks of Scotland and Ireland.

By William J. McCallien, D.Sc., Glasgow University.

Contents.

1. Introduction.
2. Dalradian Rocks in Ireland.
3. North-eastern Antrim.
4. Subdivisions of the Dalradians in Antrim.
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1. Introduction.

THE following is a tabular summary of the rocks of north-eastern Antrim.

Post-Glacial: peat, marine and fresh-water alluvium.
Glacial: boulder clay, silt, sand, and gravel.
Kainozoic: lavas and intrusions.

Mesozoic	*Cretaceous.*
	Lias.
	Trias.
Palaeozoic	*Carboniferous*: *Carb. Limestone.*
	Calcif. Sandstone.
	Old Red Sandstone: *Dingle Beds* and intrusions.

Pre-Cambrian: *Dalradian*: metamorphosed sediments and igneous rocks.

In this work the Dalradian rocks are dealt with, and the main object of the paper is to indicate a foundation for future work on the older rocks of Ireland, with special reference to their correlation with the better known members of the Dalradian in Scotland.

2. Dalradian Rocks in Ireland.

The principal outcrops of rocks of the same age as the Dalradian of Scotland occur in Ireland in the following localities :—

(*a*) Western Galway and Mayo.
(*b*) Co. Donegal.
(*c*) Co. Londonderry and Co. Tyrone (principally in the Sperrin Mountains district).
(*d*) Co. Antrim.

Other outcrops of similar rocks occur in Co. Sligo, and in Co. Londonderry east of Dungiven.

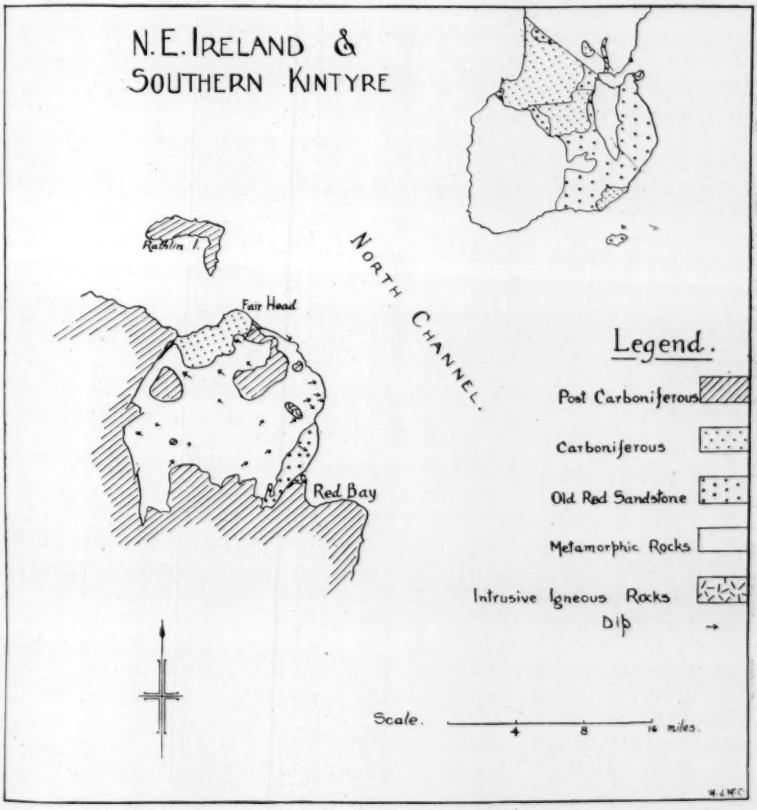


Fig. 1.—Index Map of N.E. Ireland and S. Kintyre.

In the present paper the writer deals with the rocks in (*d*) above. Fig. 1 is an index map showing the position of this isolated area of schists.

3. North-Eastern Antrim.

The older rocks of the county of Antrim are included in the one-inch maps of the Geological Survey of Ireland, Sheets 8 (Ballycastle) and 14 (Cushendall), and they are described in the memoirs [1] accompanying these maps. Little else has been published about them.

Unfortunately these survey maps are lacking in detail. In Sheet 14, for example, limestone is mapped at Torr Head and to the south-west of it; also inland in Sheet 8 at Breen and in Glenshesk, one mile farther to the south. Except for the mapping of these limestone outcrops the metamorphic rocks of Antrim are undifferentiated by the Geological Survey of Ireland.

After a study of the Dalradian rocks of Scotland extending over several years the writer now finds it possible to apply to the Irish rocks group-names which have been adopted for the Dalradian sequence in Scotland.

The rocks to be described here occur along the coast from Cushendun Bay to Murlough Bay (near Fair Head), a distance of over 7 miles. From Murlough Bay to Ballycastle the schists are overlain by the Lower Carboniferous sediments and igneous rocks of the Ballycastle coalfield and the younger sills intruded into it. From Ballycastle the boundary of the schist-area runs south-westward for 8 miles, after which it follows a zigzag course to the east and north-east, meeting the coast again at Cushendun.

In places, such as at Knocklayd (south of Ballycastle), and from Carnmore to Carnaneigh to the east, the schists are overlain by Chalk and Kainozoic lavas. Trias occurs beneath the Chalk to the north-east. The Ballycastle fault, which runs south-westward from Ballycastle, forms the north-western boundary of the schists. This fault brings down the lavas of the country to the west. To the south of the fault there are small stretches with unconformable junctions between the schists and the Chalk, and longer distances with faults. Towards the south the Antrim schists are overlain by the Mesozoic sediments and Kainozoic lavas of the rest of Antrim. In the south-eastern corner of the area the schists are separated from the Chalk and lavas by sandstones and conglomerates of Lower Old Red Sandstone age. As in Kintyre, the Old Red rests unconformably on the schists.

The district above defined as occupied by pre-Cambrian rocks is part of a range of high ground running from north-east to south-west and dissected by deep glens—the Glens of Antrim. In most of the higher parts of the district the rocks are covered with considerable thicknesses of boulder clay and peat. Inland-sections are, there-

[1] *Mem. Geol. Surv. Ireland*: (*a*) Explanation of Sheet 14 by R. G. Symes and A. McHenry, with Palaeontological Notes by W. H. Baily, 1886; (*b*) Explanation of Sheets 7 and 8 by R. G. Symes, F. W. Egan, and A. McHenry, with Palaeontological Notes by W. H. Baily, 1888.

fore, disappointing. Coastal-sections, however, are interrupted by marine alluvium only in one or two short stretches.

In the memoir on Sheets 7 and 8 it is stated that "no definite boundary can be drawn on the ground between the different varieties of schists, as they graduate imperceptibly into each other in lenticular masses".

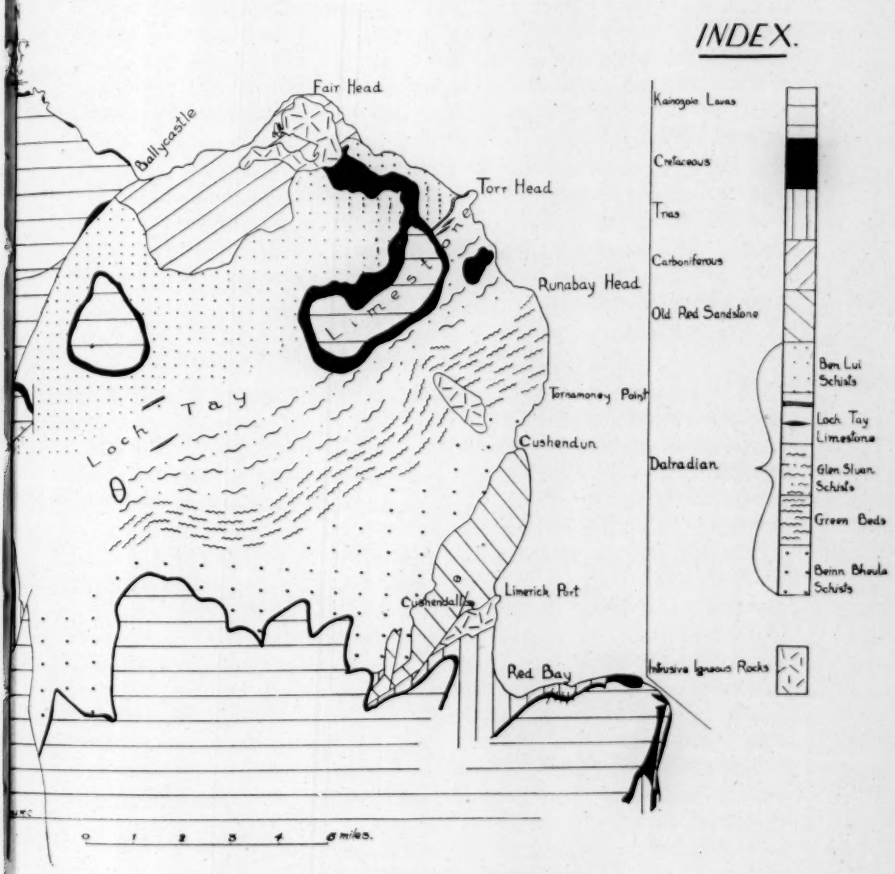


FIG. 2.—Geological Sketch-map of N.E. Antrim.

4. SUBDIVISIONS OF THE DALRADIAN ROCKS IN ANTRIM.

In Antrim the writer recognizes the following divisions of the Dalradian sequence of Scotland:—

From north-west at top to south-east at bottom:

(*e*) Ben Lui Schists.
(*d*) Loch Tay Limestone.

(*c*) Glen Sluan Schists.
(*b*) Green Beds.
(*a*) Beinn Bheula Schists and Grits.

Rocks belonging to these groups have been described by the writer from the peninsula of Kintyre.[1] The Antrim schists are separated from those of Kintyre by 12 miles of the North Channel. In the memoir on Sheets 7 and 8 it is stated that "In general character the metamorphic rocks of this part of the country resemble closely those in some portions of Co. Donegal, so that we may safely assume that the north-east corner of Co. Antrim is a portion of the old ridge of metamorphosed beds which stretched from Co. Galway, through Mayo, Sligo, and Donegal into the western and northern Highlands of Scotland in Devonian and Carboniferous times". The writer hopes to be able to make a detailed correlation of the Donegal rocks with those of Scotland on the lines of the present paper. At present all that can be said is that the rocks dealt with here are quite different from those of the northern part of Co. Donegal with which he is familiar.

(*a*) *Beinn Bheula Schists and Grits.*

These occur to the south-east and form the coast from Cushendun to a short distance north of Tornamoney Burn. Inland they occur to the west and south-west of this stretch of coastline. The rocks exposed in the coastal-section are similar to those of many sections across the group in Scotland, and in particular they remind the writer of the schists and grits along the coast of Lower Loch Fyne.

The first outcrop of the group at Rock Port, on the northern side of Cushendun Bay, consists of quartz-felspar-grits, with abundant crystals of reddish brown felspar, and muscovite-biotite-schists. Contorted quartz-veins with segregations of dark green chlorite and some felspar, as in the South-West Highlands of Scotland, are common.

The remainder of the section is composed of somewhat similar rocks with more abundant albite-schists.

The schists of the Grange of Inispollan are Beinn Bheulas, but sections are poor. The range of hills between Glendun and Glenaan is formed of rocks belonging to the same group.

At the head of Glendun, at the bridge leading over to Glenaan, are coarse albite-gneisses and schistose grits. In most of the inland exposures coarse albite-bearing rocks are the typical members of this group. Similar rocks occur at the head of Glenshesk and for about 2 miles down the glen towards Ballycastle. In this glen some of the rocks are dark greenish schists such as might be found in the Green Beds. Exposures are so few that it is difficult to map the sub-divisions of the schists in inland parts of Antrim. The Grange

[1] *Trans. Roy. Soc. Edinb.*, 1929, lvi, 2, No. 17.

of Layd is covered with boulder-clay and peat. Isolated exposures are of biotite-albite-schists, in which the albites often approach to the size of peas, and the rock then has the appearance of a schistose grit. Tourmaline is commonly found in the albite-schists.

(*b*) *Green Beds.*

Rocks belonging to this group outcrop along the coast from Runabay Head to near Tornamoney Head, a distance of about 1½ miles. Inland-sections occur along the high ground west of Aughnasillagh.

The rocks are similar to the Green Beds of S.W. Scotland. Runabay Head is composed chiefly of siliceous schists with bands of green schists. Towards the south typical Green Beds are first met with a quarter of a mile north of Tornamoney Head, where they consist of chlorite-epidote-schists and grits. Inland beyond Auchnasillagh the writer has found it extremely difficult to trace the Green Beds. The hypothetical position of the group is indicated on the accompanying map. In Glenshesk the Green Beds probably occur beneath the drift south of the Loch Tay limestone. To the north-east of this they are covered with peat to the summit of the Cushendun-Ballycastle road south of Loughaveema. In the road-sections at this part black biotite-albite-schists are worked for road metal.

The summit of Carnaneigh (880 feet) is composed of Green Beds with considerable quantities of siliceous material. The north-western margin of the group is drawn on the north-western side of the summit of this hill. From Carnaneigh to Knockmacolusky the country is composed entirely of Green Beds, which give characteristic knobbly green hills on the slopes of the main range.

In the collection of the Geological Survey of Ireland a rock from 2 miles north-west of Cushendun, which is in the writer's Green Beds, is recorded as an andalusite-mica-schist.[1] Typical rocks from the Antrim Green Beds have been sliced. They consist, as do the representatives of the group in south-west Scotland, of quartz, chlorite, and abundant epidote, with biotite, felspar, and iron ores. A schist from an exposure in Glenshesk is an epidote-biotite-quartz-albite-schist with large crystals of epidote and subordinate chlorite.

(*c*) *Glen Sluan Schists.*

This band is apparently broader across the strike in Antrim than in Kintyre. This may be due to the relation of the topography to the dip. A good section is obtained along the shore of Loughan Bay, and from Runabay Head to Portmore. The rocks are coarsely banded biotite-grits and biotite-albite-schists, with siliceous bands, and sills of epidiorite.

[1] Information kindly supplied to the writer by the Director of the Geological Survey of Ireland.

South of the sill of epidiorite in Portaleen Bay are schistose grits, followed, at Leckpatrick Point, by a massive epidiorite. These rocks are associated with bands of green schist with albite. Southward from the last locality the section consists chiefly of grits.

(*d*) *Loch Tay Limestone.*

This group occurs on the shore at Escort Port, and from there it occupies the cliffs to near the coast guard station on Torr Head. As in Scotland it is associated with epidiorite, which forms Torr Head, the high ground at the signal station, and the coast on the eastern side of the headland as far as Portaleen Bay. The writer has not seen the limestone mapped on the one-inch map on the southern side of Torr Head.

The writer thinks that the limestone (9 feet thick) a little east of Breem is the Loch Tay Limestone. Chiefly because of this correlation he thinks that the schists to the north-west of the limestone as far as Ballycastle belong to the Ben Lui group.

In the memoir on Sheets 7 and 8 it is stated that the limestones which occur in the epidiorite are of very striking and unusual character. Some bands to the south-west of the village of Torr are composed almost entirely of black calcite " which at first sight gives the rock the appearance of a dolerite ".

(*e*) *Ben Lui Schists.*

The schists along the coast north-west of the Torr Head limestone are difficult to study. West of Portadoon beneath the Chalk escarpment there is a good section in green schists dipping north-west with the remainder of the schists. From here to Ruebane Head and Murlough Bay are cliff-sections in silvery mica-schists with some grit bands. At Portadoon are greenish mica-chlorite-schists. From Portadoon towards the north-west the dip is to the north-west. From Portadoon to near Escort Port the rocks along the coast at sea-level are, on the whole, flat with dips sometimes in one direction, sometimes in the other. From Torr Head to the south the dip is to the east.

There is, therefore, in this part of Antrim an anticline with axis striking south-westward. The structure of the Antrim schists is left until further light is obtained on inland-sections.

In the railway cutting near Ballycastle are soft phyllitic mica-schists with gritty bands and bands of quartzite with white mica. The quartzite, though probably not within the Erins Quartzite group, is similar to the siliceous bands in the Ben Lui Schists near the boundary with the Erins Quartzite.

Schists in the river east of Torleige (4½ miles south-east of Ballycastle) belong to the Ben Lui Schists. They consist of soft phyllitic mica-schists and quartzose bands dipping downstream at about 30°.

Miss Reynolds in " The Petrography of the Triassic Sandstone of

North-East Ireland",[1] states that the exposure of sandstone in Murlough Bay contains pebbles of brown quartzite which "have evidently been derived from the underlying Dalradian".

5. Conclusion.

In this paper, which deals particularly with the eastern part of the Antrim schists, the writer makes the first detailed correlations of the Dalradian rocks of Ireland with those of Scotland, and thereby indicates a starting point for future correlations. He also desires to make acknowledgment for a grant towards travelling expenses in Ireland from the Carnegie Trust for the Universities of Scotland.

Pleistocene Mammalia from Nyasaland and Tanganyika Territory.

By A. Tindell Hopwood, M.Sc., F.L.S.

(Published by permission of the Trustees of the British Museum.)

AMONG the recent additions to the collections of the Geological Department of the British Museum are two small consignments of fragmentary bones and teeth from the Directors of the Geological Surveys of Nyasaland and Tanganyika Territory. They are badly weathered, but, even though generic identification is alone possible, remains of fossil mammals from these areas reach Europe so seldom that the genera represented are worth placing on record.

(*a*) Bones and Teeth from Lake Nyasa.

This is the second collection from the Chiwondo Beds of Uraha Hill, Lake Nyasa, to reach this Museum. The first was brought home by Dr. F. Dixey in 1926; I described it in 1927 (*Quart. Jour. Geol. Soc. London*, lxxxiii, 1927, 442–4). It contained *Hippopotamus*, and some pieces of dentine and enamel which I referred to a bunolophodont *Mastodon*. On this evidence a Pliocene age was suggested for the beds.

The present collection contains more *Hippopotamus*, including a well-preserved tibia, as well as *Giraffa*, and a large *Hylochoerus*. There are no additional specimens of *Mastodon*, but the proboscideans are represented by fragments of a tooth of a primitive elephant. This elephant was of the type with low-crowned teeth, widely spaced plates, and with thick enamel which was not crimped, and only slightly festooned.

[1] Geol. Mag., LXV, 1928, 458.

(*b*) Bones and Teeth from Tanganyika Territory.

The material from Tanganyika Territory was collected by Mr. Grace, a member of a private survey conducted by Dr. E. Parsons. It was sent home for identification by Dr. E. O. Teale. The specimens were obtained from fresh water beds, probably of lacustrine character, at the south-westerly end of the Wembere depression and about eighty miles in a north-easterly direction from Tabora. They are the first specimens from that region to be received in the British Museum.

By far the greater number of fragments are referable to a species of *Hippopotamus*, probably *H. amphibius*, but there are also remains of a brachyodont antelope of medium size, as well as part of the lower jaw of a juvenile elephant. The last is of great interest and importance, because it shows parts of the first four ridges of the first lower molar, and, immediately in front of that, the two last ridges of a fourth lower premolar still *in alveolo*.

Elephas sp.

Material.—Part of a left lower mandibular ramus with the broken fourth lower premolar *in alveolo*, and the first three and a half ridges of a half-worn first molar.

Horizon and Locality.—Pleistocene, Wembere Depression, Tanganyika Territory.

Description.—The premolar tooth is represented by the last two ridges. The anterior ridge is divided into two parts by a wide, deep, median cleft. Each half ridge consists of two tall, slender, closely adpressed cones; the ridge as a whole is concave anteriorly. The hinder ridge has the same construction but the cones are shorter and not so slender, and the median cleft is not so wide. Immediately behind the last ridge, and partially closing its median cleft, is a small, relatively stout cone. The maximum dimensions of the tooth as preserved are: Length, 18 mm.; breadth, 21 mm.; height, 17 mm.

The first molar is badly damaged. It is characterized by its wide, oblong, enamel figures with a slight median expansion, which are widely spaced. The enamel is almost smooth, and not festooned. Owing to damage there are no reliable dimensions available other than the width (42 mm.) at the second plate. The length exceeded 90 mm., of which about 50 mm. were occupied by the first three plates and anterior talonid, and the height of the partly worn third plate is approximately 28 mm.

Discussion.—In dealing with a fragment such as this the determination of the position of the teeth is of great difficulty. The position of the anterior tooth, and the presence of a portion of the root of another tooth cemented to the alveolar wall in front leaves no doubt that the small, unerupted tooth was in vertical succession

beneath a milk tooth, and that hence it belongs to the premolar series. Exploration beneath the tooth which is in wear failed to reveal any trace of another tooth below it, so that one concludes that the premolar is the fourth, and that the cheek-tooth is the first true molar.

This specimen is the third in which a lower premolar has been found. The other two, both of which are preserved in the Geological Department of the British Museum, regd. nos. 48931, M3079, are from the Siwalik deposits of India, and are referred to *Elephas planifrons*. The latter has the hinder portion of the fourth premolar *in alveolo*. Comparison with the African specimen shows that *E. planifrons* had the larger tooth, though the greater size of the first true molar in that species suggests that this was due to the difference in size of the two individuals. Apart from this, however, *E. planifrons* does not show the median cleft found in the African specimen, and the cones appear to be relatively stouter.

It is not possible to determine the species to which this specimen belongs, but comparison with teeth of other species seemed to afford a certain amount of information which is given here for what it may be worth. The obvious species for comparison is *Elephas antiquus recki*, remains of which are widely distributed in Central Africa. This specimen does not belong to that species, however; the plates are too widely spaced, the enamel is not so crenulate, and the mesial expansion of the enamel figures is not so distinct. Comparison with a specimen of *E. meridionalis* (regd. 28824 B.M.G.D.) from the Val d'Arno is more instructive. This tooth is the last milk molar and it agrees tolerably well with the first molar in the African specimen. The chief differences lie in the greater narrowness, and somewhat thicker enamel of the latter; the spacing of the plates is practically identical in the two specimens. This suggests a possible connection with the form from Kaiso which I (1926. *Uganda Prot., Geol. Surv. Dept., Occ. Pap.* 2, Geol. Palaeont. Kaiso Bone-Beds, 33–5, pl. iii, fig. 2) described as *Elephas* aff. *meridionalis*.

None of the fossils from Nyasaland or Tanganyika give any very precise information concerning the date of the deposits in which they were found. Beyond the fact that they are Pleistocene we know nothing as yet. It is to be hoped that additional collecting will be done in both localities, and especially at Uraha Hill. To have a deposit which is Pliocene from one set of fossils, and Pleistocene from another, is a most unsatisfactory position which can only be cleared up by careful stratigraphical collecting.

In conclusion I would express my very hearty thanks to Drs. Dixey and Teale for allowing me to examine these specimens, which they have presented to the Geological Department of the British Museum.

A Comparison of the Methods of Heavy Mineral Separation.

By C. J. C. Ewing, B.Sc., King's College, London.

1. Introduction.

METHODS and apparatus used in the isolation of heavy minerals vary considerably with different workers and this lack of uniformity obviously reduces the value of the conclusions in a branch of petrology in which quantitative data are essential. Panning in water and separation in bromoform are probably the two methods most widely adopted; but even with these there is considerable variation in the apparatus, each investigator using his own special panning device or type of separator. Also, whereas some writers employ direct bromoform separations, others treat the sediment by preliminary panning, and still others are content with panning alone. A paper published recently by Dr. F. Smithson[1] showed the effects of panning on a crushed sandstone from the Yorkshire Trias and the results were compared with those of direct bromoform separations. The divergence of results was so great that it seemed worth while to carry out a similar type of investigation on some normal unconsolidated sands in which the heavy residue makes up about 0·2 to 0·3 per cent of the total bulk. The samples used in this case were mostly from the northern outcrop of the Folkestone Sand in the Weald, but some samples of Eocene Sands from the Continent were also examined.

2. Methods.

In most cases, four samples, each of ten grams, were weighed out, and then the first and the third were used for a bromoform separation, and the second and the fourth were treated by panning followed by a bromoform separation. Averages of the first and the third were adopted and also averages of the second and the fourth, in order to guard against dry separation by shaking and settling, a process which undoubtedly occurs if the samples are stored for any length of time. Bromoform separations were carried out in filter funnels with a short length of rubber tubing and a clip at the base. Constant stirring was employed to ensure as complete separation as possible. This method is recommended by A. Holmes in *Petrographic Methods*, by T. Crook in *Economic Mineralogy*, and by H. B. Milner in *Sedimentary Petrography* and seems to have a fairly wide use.

Both unprepared and washed samples were used in these separations and although no appreciable differences were apparent in the figures, it seems as though washing assists the process, especially if there is much fine material present. Panning was done in an ordinary 9 in. evaporating dish with no inward turned rim or grove near the

[1] Geol. Mag., LXVII, 1930, 134–6.

edge. It might be thought at first that this would allow a great loss of the heavy material, but actually, the steepening of the sides of the dish (in an approximately logarithmic curve) is quite sufficient to hold the grains in. In most cases a single careful panning was considered sufficient, but, as a check, some samples were panned three times. The process was not carried to the stage of complete separation of the heavy minerals and the residue from panning was usually between 5 per cent and 10 per cent of the original by weight. This residue was dried and then passed through bromoform in the usual manner. To provide a check on the original bromoform separations the "light" fraction was panned down and again passed through bromoform—the residue being mounted as a special part. These results have been plotted graphically (Figs. 1, 2, 3). The whole of the residue was mounted in each case and counting was assisted by the use of a mechanical stage. Further it has proved possible to devise an effective counting mechanism which greatly expedites the work of counting and reduces the strain on the eyes. It consists of a set of keys—one for each mineral, each one operating a "Veeder Counter". The keys can be worked by the right hand, once the positions have been learnt, and the left hand is free to work the stage or the Nicols. Each mineral is counted as it passes the vertical cross-wire; if a number come under the cross-wire at one time, then they are counted from the top to the bottom of the field —the whole of the slide being examined and not a series of fields. This method entails rather careful mounting to ensure that grains are not lost during transference and that their distribution is even.

3. Results.

The following table shows a comparison of panned and bromoform results with the figures for the opaque grains omitted. These have been omitted because they can only be identified in reflected light and most of them are limonite, which, in certain cases has flooded samples without affecting the other minerals.

Table Showing Comparison of Panning and Bromoform Results.

	36B	38A	38C	43A	44C	49B	B.L2-2	M.L2	BL2	Mean	ratio
Zr.	64	77	76	61	76	67·5	79	68·5	87	Pa.	1·10
	53·5	68	68	60	73·5	66·5	65	65	78	Br.	
Ru.	8	8	8	12·5	8·5	12·5	11	9·5	9·5	Pa.	0·91
	9	9	13·5	7·5	10·5	9	11	12·5	14·5	Br.	
St.	6·5	3	6·5	5	4	4	2·5	6·5	0·5	Pa.	0·99
	6·5	4·5	4	6	3	4·5	3·5	6·5	0·5	Br.	
Ky.	12·5	6	6	10	6	8·5	3	5·5	1·5	Pa.	0·80
	17·5	9	8	12·5	5·5	7·5	8·5	3	2·5	Br.	
To.	9	6	3·5	11·5	5·5	7·5	4·5	10	1·5	Pa.	0·61
	13·5	13	6·5	14	7·5	12·5	12	13	4·5	Br.	

Zr = zircon; Ru = rutile; St = staurolite; Ky = kyanite; To = Tourmaline; Pa. = panned and bromoformed; Br. = bromoformed.

List of localities :—

Folkestone Sand.	36B.	Limpsfield Common.
	38A.	Rook's Nest.
	38C.	Godstone.
	43A.	Buckland Sandpit.
	44C.	Small section north of Betchworth.
	49B.	Leasers' Barn pit, north of Abinger Hall.
Upper Landenian.	B.L2–2	Wilderen (France.)
	M.L2	Sorrus (France.)
	B.L2	Montigny (France.)

The mean ratio is obtained by dividing the mean per cent panning results by the mean per cent of the bromoform figures.[1]

FIG. 1.

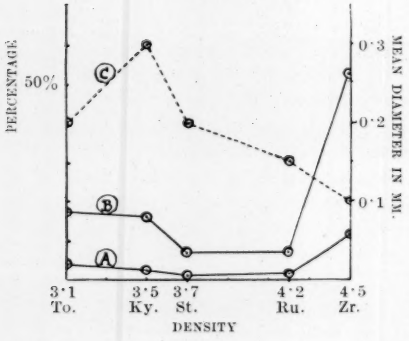


FIG. 2.

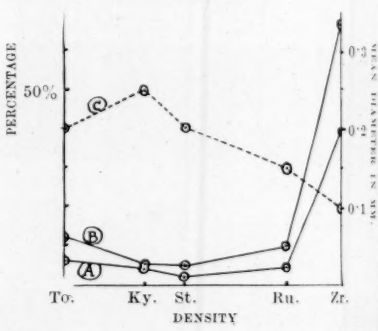
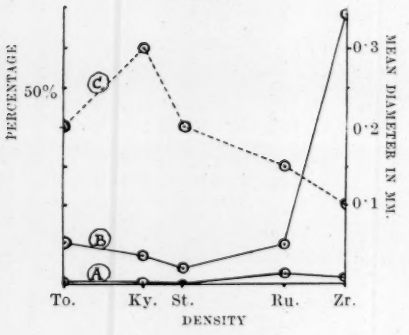


FIG. .3.



FIGS. 1, 2, and 3 show in each case: A, the percentage held up in bromoform; B, the total percentage present; and C, the sizes of the grains.

FIG. 1.—Buckland Sandpit sample.
FIG. 2.—Sample from Sorrus.
FIG. 3.—Folkestone Sand.
(Average of 3 samples.)

To. = Tourmaline.
Ky. = Kyanite.
St. = Staurolite.
Ru. = Rutile.
Zr. = Zircon.

[1] It will be noticed that the figures have been taken to the nearest 0·5 per cent. It is obviously impossible to work to an accuracy entailed by the first decimal point, but in the case of the smaller numbers, approximation to the nearest whole number is more serious than with the larger numbers, so a compromise has been adopted, and all figures are taken to the nearest 0·5 per cent.

It can readily be seen that the figures are only representative for zircon, staurolite and tourmaline. The ratios for rutile and kyanite can be changed completely by the removal of the figures of any one of the samples ; but on the other hand, the ratios for zircon indicate the consistent excess in panned results ; those for staurolite, the close similarity between the figures ; and those for tourmaline, a consistent loss in panning.

The excess of zircon in the panned residue might at first be thought due to the forcing up of the percentages by a great loss of tourmaline ; but a direct test on the quartz left over from the bromoform separation showed that zircon was actually being held up in considerable quantities. The accompanying curves have been constructed so that the upper one represents the total percentages of each mineral discovered, *i.e.* the total of the grains from the " light ", as well as the " heavy ", fractions ; the lower curve shows the fraction of the percentages recovered from the " light " crop and the dotted line represents the average size of the grains—obtained by measurement of a large number in the various slides. In each case, staurolite shows the least loss and in two cases the order is as follows :—

Staurolite, rutile, kyanite, tourmaline, and zircon, the last showing the greatest loss of all. In the third curve (an average of three Folkestone Sand samples), zircon does not show the usual high loss, but falls to a value below that of rutile—no explanation of this is apparent.

The factors affecting the retention of the grains in the " light " crop seem to be : size, density, surface-tension and the time factor. On the one hand there is zircon with an average diameter of 0·1 mm. playing an interstitial rôle between the larger quartz grains and thus mechanically impeded from sinking ; whilst on the other hand there is tourmaline with a density only slightly greater than that of bromoform and in addition a " flat-faced " form of grain—both factors affecting its flotation and thus causing partial exclusion from the " heavy " crop. It is clear that if the separation could be allowed indefinite time with constant stirring, sooner or later every heavy grain would work its way down to clear bromoform, and then would sink unimpeded. Thus the theoretically ideal separation would be one in which the quartz layer was only one grain in thickness and only the very slightest impedance could occur. Staurolite is neither very small nor of low density, and in each case it shows practically no loss as between the panned and the bromoform samples, so that evidently it is practically immune from loss during panning as well. These results have only been obtained for the filter-funnel type of separator, but the effects must be practically the same in every type of apparatus.

In panning one of the most important considerations to take into account is that of the " personal factor ". Tests have shown that losses are incurred during panning and it is hoped to publish some figures at a future date. The importance of the " personal factor "

becomes obvious when comparisons are made between different workers' results. In any one investigator's results, the results are probably of an order which would not affect the accuracy of the figures ; but when comparison is made with those of another worker, the " personal factor " may lead to incorrect conclusions. A uniform method of separation is highly desirable and probably the best method would be a compromise between panning and bromoform separation.

If panning were utilized to reduce the bulk to, say one-half or one-third, the loss of heavy minerals would not be very great, because it is in the final stages of the process that the losses become of real importance. Then samples could be dried and passed through bromoform in the usual way. The losses in bromoform would be reduced by the absence of much quartz.

This method is probably the one used by quite a number of investigators ; but it is important to ensure that panning is not carried to a degree which in any way jeopardises the results to be obtained after bromoform separation.

REVIEWS.

HANDBOOK OF CORNISH GEOLOGY. By E. H. DAVISON. Second edition, pp. 110, with plates, text-figures, and a map. Truro : Oscar Blackford, 1930.

THE first edition of this admirable small book was reviewed at some length in this Magazine on its appearance in 1926. The chief changes introduced in this new edition are a new chapter on China Clay, and additional illustrations, maps, and sections. But the whole has been mostly carefully revised, chapters vii, viii, and ix being to a considerable extent rewritten. From his long experience as a teacher and a mining geologist, Mr. Davison is of all men the most competent to deal with the subject from both the theoretical and the practical points of view, and he possesses the gift of setting out his knowledge in a simple and easily intelligible form. The book can be most strongly recommended to those interested in the geology of Cornwall and in the industries carried on in that county based on its mineral wealth. It cannot fail also to be of great value to students who desire to get a grasp of the type of geological knowledge essential to an intelligent appreciation of the special problems of mining geology, while the more general aspects of the geological history of the region also receive adequate recognition. It is, however, melancholy to reflect on the depressed condition of tin-mining at the present time in comparison with the conditions of the middle of the nineteenth century, when Cornwall was one of the leading mining districts of the world.

INTERNATIONAL GEOLOGICAL CONGRESS, SOUTH AFRICA, 1929. Compte Rendu. Two vols, pp. 314 + 688, with 42 + 97 plates, 2 + 33 text-figs. Pretoria: Wallachs, Ltd., 1930. Price £2.

IT is manifestly impossible to review a publication of this kind in the ordinary sense of the word, owing to the comprehensiveness and variety of its contents. Apart from the official memoranda of the Congress, the volumes contain a great number of original papers in five languages dealing with the special subjects chosen for discussion on this occasion. Among these the geology of South Africa in the broadest sense of that geographical expression naturally claims the first place. Nevertheless there are many notable contributions on other branches of geological science. It may be noted that papers in the newly admitted languages, Spanish and Italian, are here accompanied, in deference to the weaker linguistic brethren, by summaries in English. Some of these might perhaps have undergone a little more editing with advantage, while the abrupt changes of language in the course of many of the official reports are occasionally disconcerting.

However, since these large and beautifully illustrated volumes are necessarily rather expensive, it is believed that it may be useful to geologists in many parts of the world to have a summary of what they contain, so no further apology is here offered for the following reprint of some pages, namely the table of contents of volume ii. The first volume is entirely occupied by minutes of proceedings and other such matter, including long reports of the excursions.

Section I.—Magmatic Differentiation.

1. P. NIGGLI. "Principielle Bemerkungen zum Problem der magmatischen Differentiation."
2. T. KATO. "The last Stage of Magmatic Differentiation as represented by Tertiary Gold Silver Veins."
3. A. P. COLEMAN, E. S. MOORE, and T. L. WALKER. "The Sudbury Nickel Intrusion." [Abstract only.]
4. A. DEMAY. "Sur les Transformations Hercyniennes d'Origine dynamique dans les Cevennes et dans le Massif des Maures."
5. A. W. VLASENKO. "Genesis der Eisenerze der Abakan'schen Eisenhütte."
6. E. REUNING. "Differentiation der Karroo-Eruptiva im südlichen Kaokoveld, Südwest Afrika."
7. E. REUNING. "Differentiation und Differentiationsprobleme südafrikanischer Gesteinsmagmen."
8. S. VARDABASSO. "Rapporti fra attivita magmatica e vicende tettoniche nella provincia petrografica di Predazzo (Trentino, Italia)." [And Abstract in English.]

Section II.—Pre-Pleistocene Glacial Periods.

9. M. GORTANI. "Deriva dei Continenti e Periodi Glaciali." [And Abstract in English.]
10. E. NORIN. "An Occurrence of late Palaeozoic Tillite in the Kuruk-Tagh Mountains, Central Asia."
11. H. G. BACKLUND. "On a probable tillite of late Palaeozoic age from the Kara River, northernmost Ural."
12. A. W. ROGERS. "Pre-Cape Tillites in the Union of South Africa."

13. S. H. Haughton. "The Glacial beds in the Table Mountain Series."
14. A. L. du Toit. "A brief Review of the Dwyka Glaciation of South Africa."
14*a*. J. Nicolaev. "Glacial Deposits—Tillites—of Lower Cambrian Age in the Yenisei Ridge."

Section III.—The Karroo System; its Stratigraphy, Palaeontology and World Distribution.

15. P. Range. "Beiträge zur Fauna und Flora der Karruformation Südwestafrikas."
16. H. Besairie. "Les Formations du Karroo à Madagascar."
17. F. Dixey. "The Karroo of the Lower Shire-Zambezi Area."
18. F. Dixey. "A Provisional Correlation of the Karroo north of the Zambezi."
19. A. B. Walkom. "A Comparison of the Fossil Floras of Australia with those of South Africa."
20. P. Fourmarier. "Le Système du Karroo au Congo Belge."
21. A. Chiarugi. "Contribuzione alla Palaeoxilologia dell' Africa." [And Abstract in English.]
22. J. Lombard. "Sur une transformation métasomatique particulière des grès supérieurs du bassin du Congo." (Formations synchroniques du Karroo.)
23. F. Mouta and A. Borges. "Sur l'existence et la distribution du Karroo dans l'Angola." (Districts de l'Est et du Nord.)
24. E. O. Teale. "A consideration of the term Tanganyika System with special reference to the Ujiji and Uha Regions."
25. H. H. Thomas. "Notes on the Investigation of the Spore Content in certain Karroo Rocks."
26. G. Stefanini. "Successione ed Eta della 'Serie di Lugh' nella Somalia Italiana." [And Abstract in English.]
27. A. L. du Toit. "A short Review of the Karroo Fossil Flora."
28. S. H. Haughton. "The Origin and Age of the Karroo Reptilia."
29. F. P. Mennell. "The Karroo System in East and Central Africa."

Section IV.—The Genesis of Petroleum.

30. P. Krusch. "Die Entstehung des Erdöls, verwandter Kohlenwasserstoffe und gewisser Kohle."
31. F. Secco. "L'Origine del Petrolio." [And Abstract in English.]
32. E. Seidl. "Entstehung von Erdöl aus Steinkohle in tief versenkten Druckgebieten der Erdrinde." [Abstract only.]
33. R. Fabiani. "Idee sulle Pronienza degli Hidrocarburi di Sicilia." [And Abstract in English.]

Section V.—The Geological Work of Micro-organisms.

34. G. Bargagli-Petrucci. "Sull' Origine Biologica dei Depositi di Ferro e di Solfo." [And Abstract in French.]
35. E. Onorato. "Sulla natura e genesi della Pelagosite." [And Abstract in English.]

Section VI.—Rift Valleys.

36. E. J. Wayland. "Rift Valleys and Lake Victoria."
37. D. Johnson. "Geomorphic Aspects of Rift Valleys."
38. H. Cloos. "Tektonische Experimente und die Entstehung von Bruchlinien (Rift Valleys)." [Abstract only.]
39. E. Seidl. "Rift Valleys (Grabenbrüche) in Mittel-Europa."
40. W. von Seidlitz. "Grabentäler und Bruchzonen in Mittel-Europa und Vorderasien."
41. J. V. Harrison. "The Magdalena Valley, Colombia, South America."
42. J. J. Pannekoek van Rheden. "Map of the Pre-Pleistocene Subsoil of South Limburg (Netherlands)."

Section VII.—General.

43. N. R. Junner. "The Norite of Sierra Leone."
44. J. v. Szadecsky. "Assimilations Erscheinungen in dem Harghitazuge der Ostkarpaten und über die Enstehungsweise des Diamantes im Bereiche der Alkaligesteine."
45. H. Cloos. "Alter und Verband der Jungen Granite in Südwestafrika." [Abstract only.]
46. V. Zsivny. "Über den Veszelyit."
47. P. Kovaloff. "Notes on the Beryl Occurrences in Namaqualand."
48. L. Joleaud. "Contribution à l'étude des gîtes de plomb de la Tunisie Septentrionale."
49. H. J. Schuiling. "The Structure of the Kambove Mine."
50. K. Kinoshita. "On the Genesis of the 'Kurumono' deposits."
51. F. Schumacher. "Über bergbauliche Möglichkeiten und einige wenig bekannte Erzvorkommen in der Turkei."
52. J. Thoreau. "Les mineralisations cuprifères de la zone frontière Katanga-Rhodésie."
53. P. Russo. "Observations et Hypothèses sur les Rapports du Rif, de la Cordillère Bétique et de l'Atlas."
54. L. Maddalena. "Studi Geologici inerenti alla Costrusione della Grande Galleria Attraverso l'Appennino Tosco—Bolognese per la Linea Direttisima Bologna—Firenze." [And Abstract in English.]
55. R. Fabiani. "Erusioni sottomarine in Sicilia durante il Giurese." [And Abstract in English.]
56. R. Fabiani. "Analogie tettoniche fra la Sicilia e la Tunisie." [And Abstract in English.]
57. O. Pratje. "Die geologische Erforschung des Südatlantischen Ozeans durch die Deutsche Atlantische Expedition."
58. F. Blondel. "État de nos connaissances en 1929 sur la Géologie de l'Indochine française."
59. A. Demay. "Sur la Tectonique Hercynienne du Massif Central Français à l'est de la Loire."
60. C. Freire de Andrade. "An Outline of the Geology of Portuguese East Africa."
61. P. Charrin. "Application Nouvelle des Méthodes de la Polarisation Spontanée à des Études Tectoniques."
62. L. L. C. Neltner. "État des connaissances actuelles sur la géologie du Maroc."
63. E. Feruglio. "Origine delle Depressioni Chiuse della Regione del Golfo di San Giorgio" (Patagonia). [And Abstract in French.]
64. E. Feruglio. "Il Devonico della Regione Subandina dell' Argentina Settentrionale." [And Abstract in French.]
65. M. Solignac. "Description d'une Nouvelle Carte Géologique de la Tunisie a l'Échelle de 1/500,000."
66. J. G. Sineriz. "Estudio de prospeccion geofisica en Alcala de Henares (Spain) por el metodo sismico." [Abstract.]
67. J. G. Sineriz. "Investigacion geofisica en la cuenca carbonifera de Villanueva de les Minas (Spain)." [Abstract.]
68. J. G. Sineriz. "Estudia geofisico previo de la falla del Guadalquivir." [Abstract.]
69. D. Mushketov and P. Nikiforoff. "Gravimetric and Seismic Expedition to Central Asia."
70. J. V. Zelizko. "Anteil des Dr. Emil Holub an der Geologisch-Paläontologischen Erforschung Südafrikas."
71. G. de Geer. "Solar Registration by Pre-Quaternary Varve-shales."
72. P. Kovaloff. "Activity of the reorganised Russian Geological Committee (Geological Survey)."
73. H. Reich. "Über die Physikalischen Eigenschaften Geologischer Körper."